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Spectral radiance measurements in Monterey Bay.

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THESIS

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Thesis Advisor: Stevens P. Tucker

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1964

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ABSTRACT

An underwater spectral radiance meter having a rotating spectral wedge filter and capable of operating to depths of 300 meters was designed and constructed. It was used to obtain measurements of spectral radiance to a depth of 60 meters at two stations in southern Monterey Bay, California, on an overcast day during July 1971. Variations of the spectral radiance distribution with depth were plotted for vertical angles of 0, 45, 90, 135 and 166 degrees at an azimuth angle of zero degrees with respect to the sun.

The results of the measurements are reasonable in all cases and indicate that the spectral wedge filter provides a practical means of determining spectral radiance distributions.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 8

A. PURPOSE ---------- 8

B. PREVIOUS INVESTIGATIONS ---------- 8

II. EQUIPMENT ---------- 12

A. NPS SPECTRAL RADIANCE METER ---------- 12

1. Photometer Unit ---------- 12

2. Motor Housing Unit ---------- 23

3. Junction Box ---------- 23

4. Battery Supply ---------- 24

B. CALIBRATION ---------- 24

1. Azimuth and Vertical Angles ---------- 24

2. Spectral Wedge Filter ---------- 24

3. Acceptance Angle ---------- 29

4. Photometer ---------- 29

III. DATA COLLECTION ---------- 34

A. STATION LOCATIONS ---------- 34

B. OPERATIONAL PROCEDURES ---------- 34

IV. DATA ANALYSIS ---------- 37

V. CONCLUSIONS ---------- 41

APPENDIX A Figures of Spectral Radiance Distribution with Depth at $\phi = 0°$ and $\theta = 0, 45, 90, 135$, and $166°$ for Stations 1 and 2 ---------- 42

APPENDIX B Spectral Radiance Calibration Nomograms for 25 nm Wavelength Bands from 400-725 nm --------- 52

APPENDIX C Station Data: Location, Date, Time, Depth, Weather, Altitude of the Sun, Azimuth of the Sun, Radiance Measurements ------------------- 65

BIBLIOGRAPHY -- 77

INITIAL DISTRIBUTION LIST ------------------------------ 80

FORM DD 1473 -- 85

LIST OF FIGURES

Figure

1. Location of Stations in Monterey Bay ------------------- 9

2. Spectral Radiance Meter -------------------------------- 13

3. Radiance Meter Before Submergence ------------------ 14

4. General Arrangement of Radiance Meter -------------- 15

5. General Arrangement of Photometer Unit ------------- 17

6. Block Electrical Diagram of Underwater Unit ---------- 18

7. Circuit Diagram of Shipboard Recording System -------- 18

8. Spectral Wedge Filter Characteristics ----------------- 20

9. Photometer Circuitry ---------------------------------- 21

10. Overall Sensitivity Versus Overall Voltage ----------- 22

11. Photomultiplier Tube Spectral Response --------------- 22

12. Vertical Angle Calibration Curve in Downward Direction -- 25

13. Vertical Angle Calibration Curve in Upward Direction ---- 26

14. Azimuth Angle Calibration Curve ---------------------- 27

15. Spectral Wedge Filter Rotation Calibration Curve ------- 28

16. Acceptance Angle Calibration Arrangement ------------ 30

17. Acceptance Angle Calibration Curve ----------------- 31

18. System Calibration Arrangement ---------------------- 32

19. Calibration Curve for Standard Lamp ------------------ 33

20. Uncorrected Spectral Radiance Variation with Depth at $\phi = 0°$ and $\theta = 0, 45, 90, 135$, and $166°$ -------------- 35

21. Sample of Spectral Radiance Output ------------------ 38

22-31. Spectral Radiance Distribution with Depth at $\phi = 0°$; $\theta = 0, 45, 90, 135,$ and $166°$ for Stations 1 and 2 ------ 42

32-44. Spectral Radiance Calibration Nomograms for 25 nm Wavelength Bands from 400-725 nm ------------- 52

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I also wish to thank Professor Jerry A. Galt and the crew of the Naval Postgraduate School Hydrographic Boat for their assistance. Lastly, sincere thanks to my wife, Susanne, for her typing assistance, endless encouragement, and the positive manner in which she accepted my neglect during this effort.

I. INTRODUCTION

A. PURPOSE

With the increasing application of optical properties in the fields of water mass characterization, marine optical systems and biological studies there exists a strong need for more measurements of these properties and, in particular, measurements of underwater radiance with depth.[1]

The purpose of my investigation was to measure the spectral radiance distribution of submarine daylight as a function of depth in Monterey Bay, California. To acquire these measurements a radiance meter using a rotating spectral wedge filter capable of continuous rotation in the vertical and horizontal planes was constructed between January and June 1971 at the Naval Postgreduate School. Measurements of spectral distribution of submarine daylight with depth were then made to a depth of 60 meters at two stations in Monterey Bay during July 1971 (Figure 1).

B. PREVIOUS INVESTIGATIONS

Historically, initial studies of radiant light intensity in the sea began during the early 1900's when scientists were successful in measuring spectral radiance with photographic techniques. Until about 1940

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[1]Radiant intensity (of a source in a given direction) is defined as the radiant flux emitted by a source, or by an element of a source, in an infinitesimal cone containing the given direction divided by the solid angle of that cone. The unit of measurement is expressed in watts per steradian. Radiance is the radiant flux per unit solid angle per unit projected area of a surface. Its units are watts per square meter per steradian.

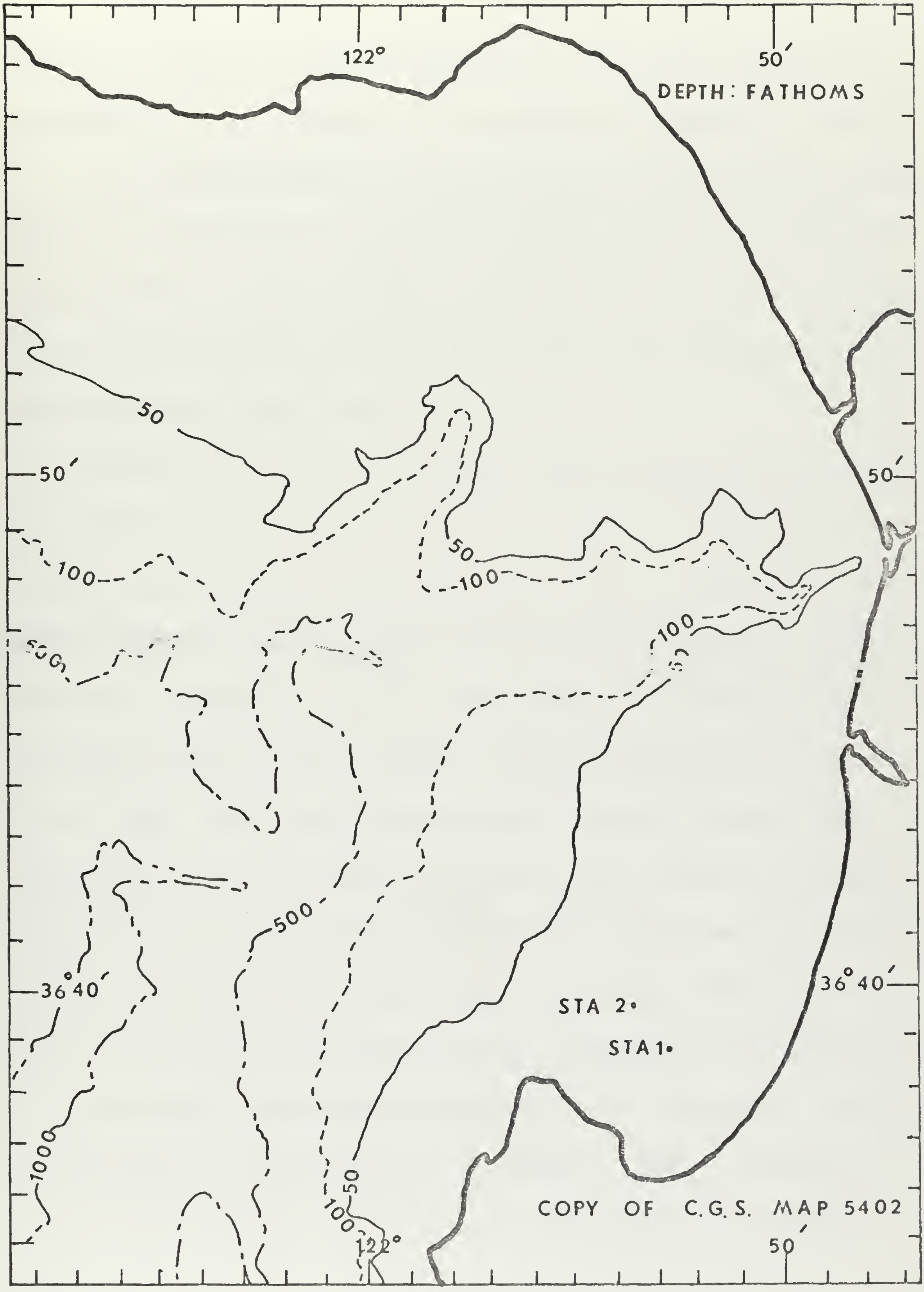


FIGURE 1. LOCATION OF STATIONS IN MONTEREY BAY

such recording systems were used to measure the variation of spectral radiance of submarine daylight with depth. Although the photographic techniques had many limitations the results were qualitatively useful.

With the development of sensitive photoelectric detectors and improvements in spectrographic instruments, the way was paved for much of the pioneer work in the field by Darby, Le Grand, Le Noble, Duntley, Jerlov, Tyler, Ivanoff, and many others. Since then, research progress has paralleled instrumental techniques.

Sasaki, et al., [1955a] initiated studies utilizing the photomultiplier tube in making radiance measurements from the underwater observation chamber KUROSHIO in Hakodate Bay, Japan. Using three Wratten gelatin filters he was able to determine the angular distribution pattern of light as a function of particular wavelengths. Employing the same photometer, Sasaki, et al., [1955b] examined natural light in the red, yellow, green, blue, and violet wavelength regions in waters of the Kuroshio Current, which enabled him to make some extinction coefficient determinations for the oceanic region. Similar studies were also being carried out by Duntley and Tyler at Lake Pend Oreille, Idaho [Duntley 1963]. The results of the latter studies supported the asymptotic radiance distribution hypothesis of the light field from the surface to great depths which was speculated by L. V. Whitney [1941]. Theoretical proof of the existence of this distribution was given by Preisendorfer [1959].

With the advent of the second generation of radiance meters, interesting studies were subsequently made by Sasaki, Tyler, Jerlov, and many others throughout the world. A cumulative analysis of all their results clearly indicates that radiance becomes more symmetrical about the vertical and horizontal axes with depth; that a strong radiance maximum exists in the apparent direction of the sun; that radiance approaches an asymptotic distribution; that the variation of sea surface, sky and turbidity of the water have a large effect on the radiance distribution; and that the light "window" in the sea is in the 480 nanometer wavelength region.

More recently, extensive studies by Tyler and Smith [1970] of spectral irradiance underwater were made during 1968 with the Scripps Spectroradiometer at six locations in the Northern Hemisphere and yielded quantitative information related to the optical attenuation properties and the spectral distribution of underwater light.

Locally, the only previous study of underwater illumination was made by Bassett and Furminger in Monterey Bay in 1964 [Bassett and Furminger 1965]. They found the diffuse attenuation coefficient (vertical extinction coefficient) to be about .090 m^{-1} at 536 nm for their Monterey Bay stations in January 1965.

II. EQUIPMENT

A. NPS SPECTRAL RADIANCE METER

A spectral radiance meter capable of continuously measuring the spectral intensity of submarine daylight over 4π steradians to a depth of 750 feet was designed by the author and Stevens P. Tucker. Since the results of Sasaki's shallow water studies [Sasaki, et al. 1955b] have shown that the direction of the maximum value of the angular distribution of submarine daylight in the horizontal plane is always identified with the solar bearing, it was decided not to include a direction sensor to determine the orientation of the meter when submerged.

The radiance meter (Figures 2 and 3) consists of three major units plus an underwater battery supply: the photometer unit, the motor housing, and the junction box. The general arrangement of the components within the meter is shown in Figure 4. A block electrical diagram of the entire underwater unit and the shipboard recording system are shown in Figures 6 and 7.

During operation the entire underwater unit is suspended from a 3/16-inch O.D., 4-conductor, armored electrical cable.

1. Photometer Unit

The photometer is housed in a 12-inch long aluminum tube having a 3/4-inch wall thickness and an inside diameter of 6 inches. The unit is attached by clamps to the horizontal shaft of the motor housing,

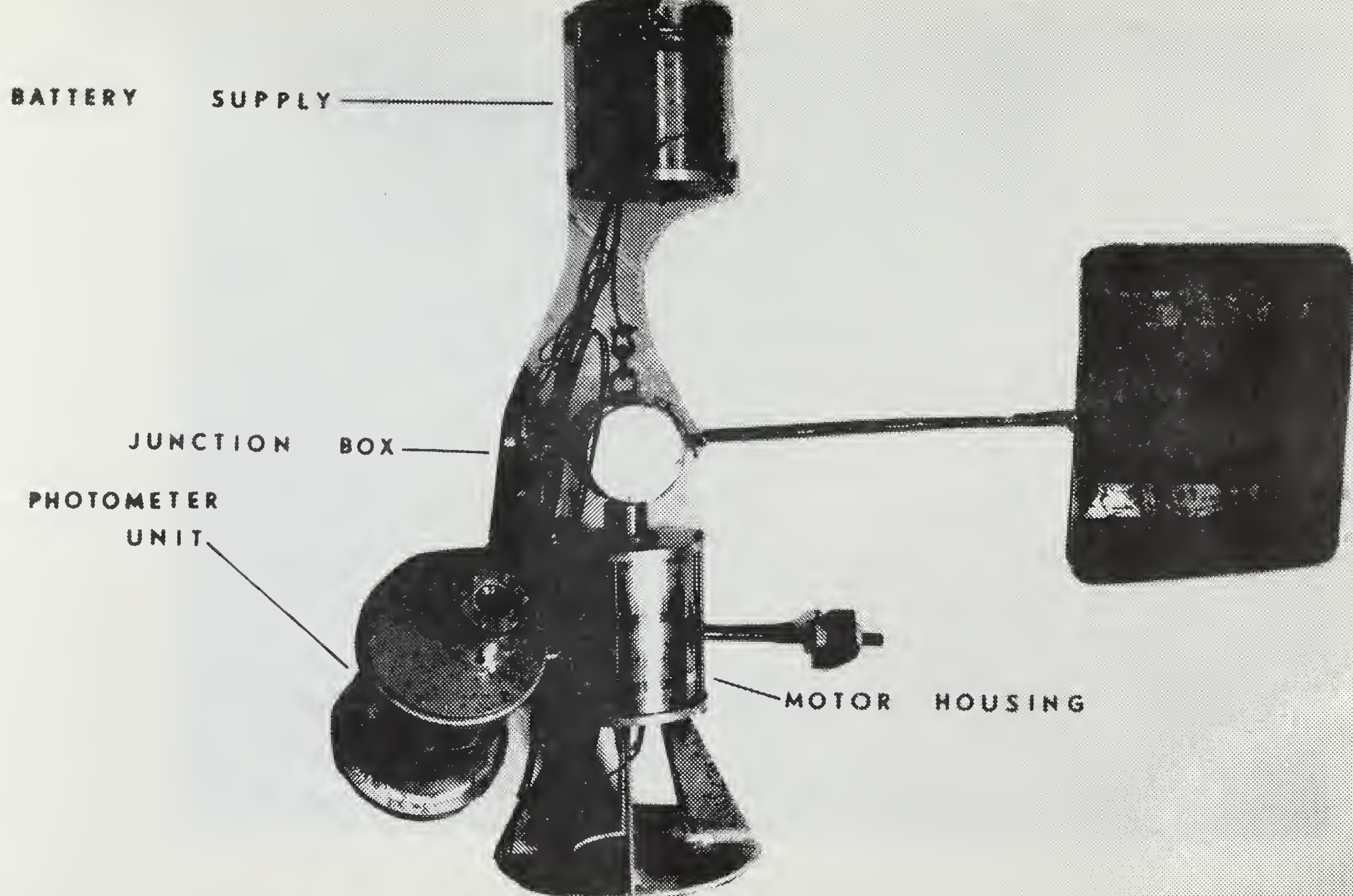


FIGURE 2. SPECTRAL RADIANCE METER

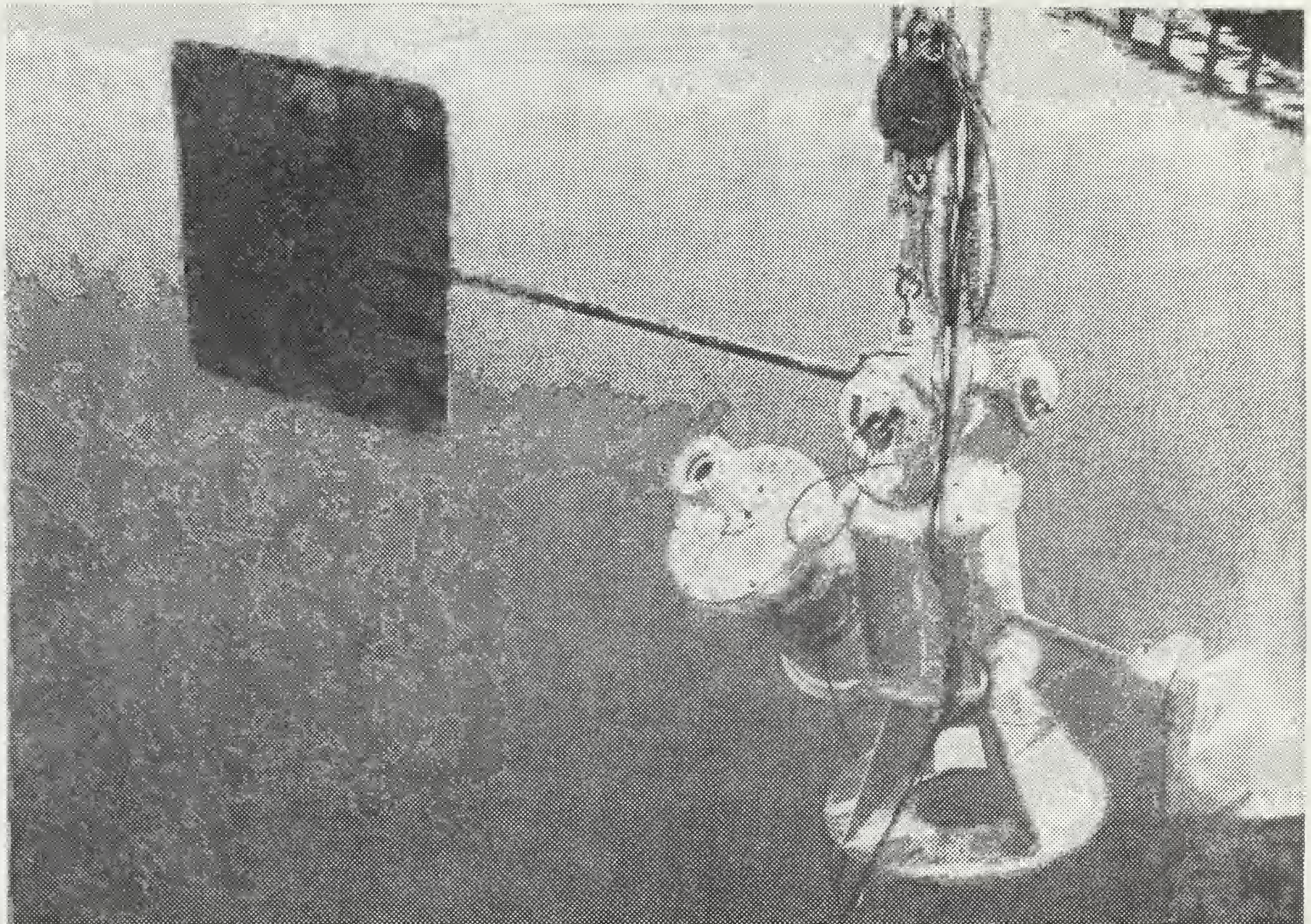


FIGURE 3. RADIANCE METER BEFORE SUBMERGENCE

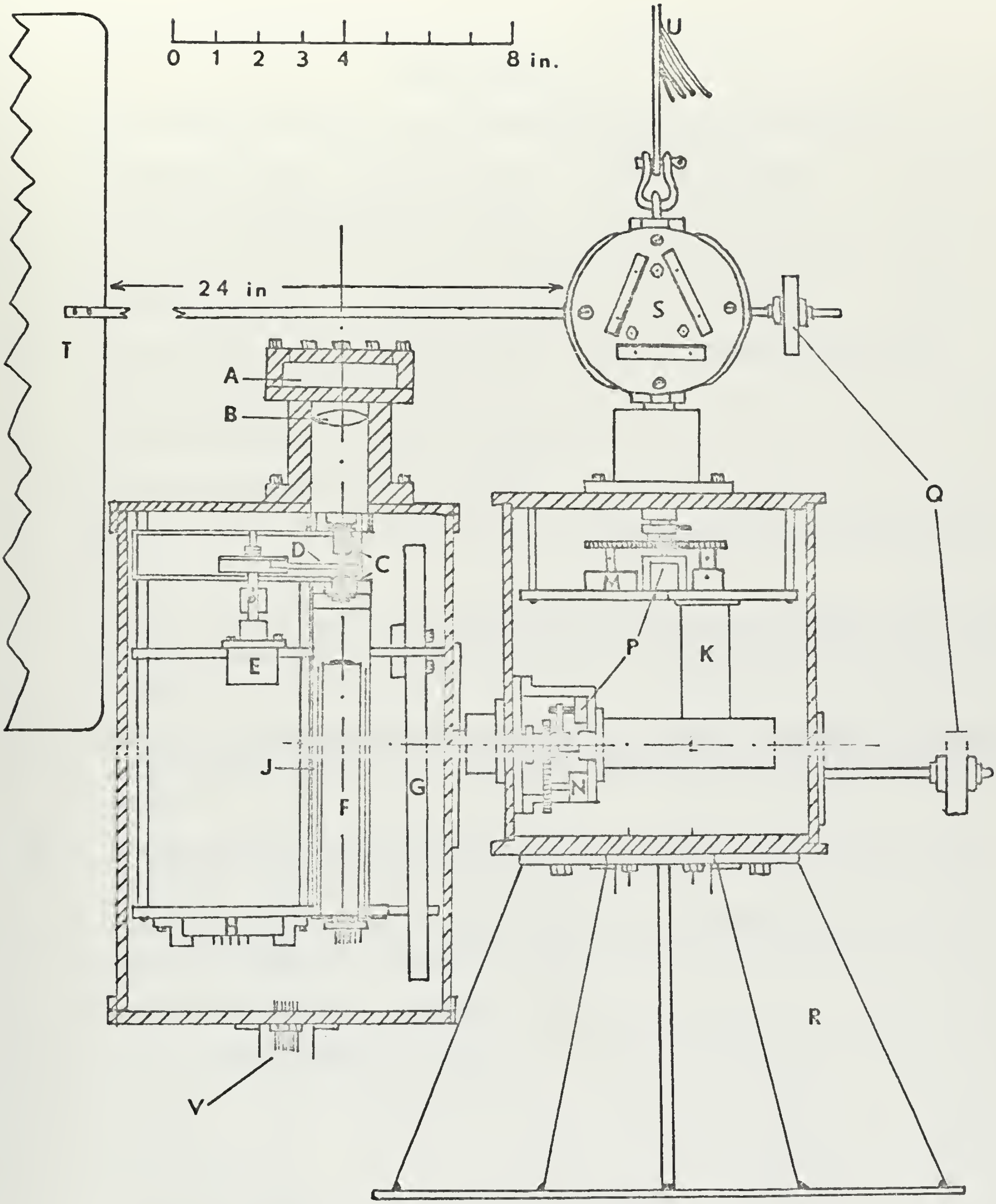


FIGURE 4. GENERAL ARRANGEMENT OF RADIANCE METER
(SEE PAGE 16 FOR KEY)

Key to Figure 4

A. One-half inch thick clear Pittsburgh plate glass window.

B. Achromatic lens, 33m diameter, 100mm focal length.

C. Achromatic microscope objective, 3mm focal length.

D. Spectral wedge filter, 4-inch diameter, 180° segment. (Optical Coating Laboratory, Inc.)

E. Filter drive motor, Model 41-25, 42 rpm, 35 v reversible D.C. (Hansen Manufacturing Co.)

F. Photomultiplier tube (EMI 9524B).

G. Electronic circuitry for PM tube.

H. Burr-Brown Model 520/25, $\pm$15 volt dual regulator power supply.

J. Mu-metal shield.

K. Geared 26vdc motor, Globe Model C5A1106, reversible, 24,000rpm nominal with 4126:1 gear reducer, 500 oz-in maximum continuous torque.

L. Geared 26vdc motor, Globe Model C5A1092, reversible 24,000rpm nominal with 2273:1 gear reducer, 370 oz-in maximum continuous torque.

M. Potentiometer, azimuth angle (ϕ), Model 130 SRD, 10K, 0.5% linearity. (Spectral Instrument Co.)

N. Potentiometer, vertical angle (θ), Model 130 SRD, 10K, 0.5% linearity. (Spectral Instrument Co.)

P. Reversing switches, DPDT.

Q. Lead counterbalance weights.

R. Stand.

S. Junction Box.

T. Aluminum Rudder (20 inches X 19 inches).

U. Three-sixteenths inch, 4-conductor, externally armored, well logging cable.

V. Mecca No. 2047 seven-pin underwater electrical connector.

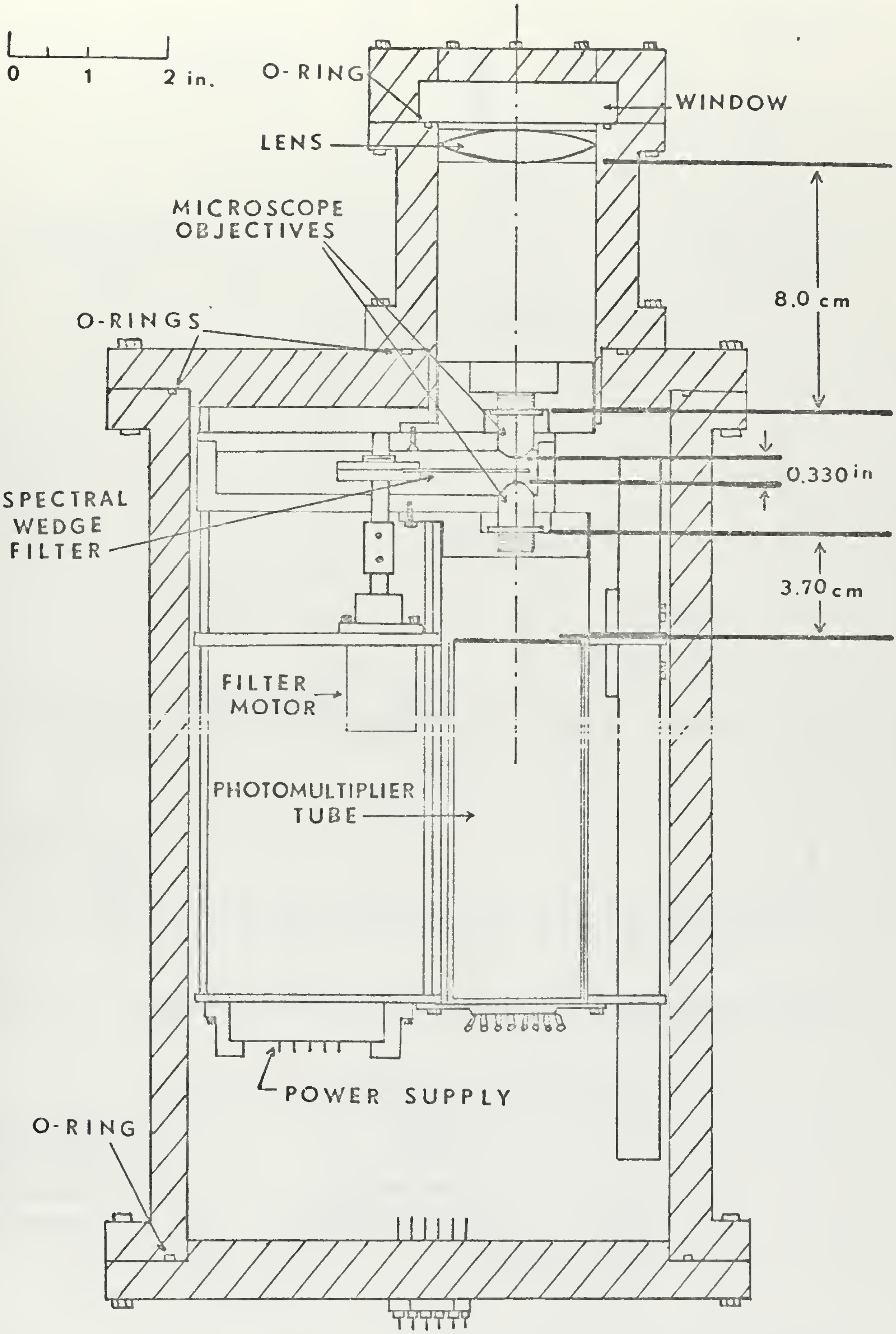


FIGURE 5. GENERAL ARRANGEMENT OF PHOTOMETER UNIT

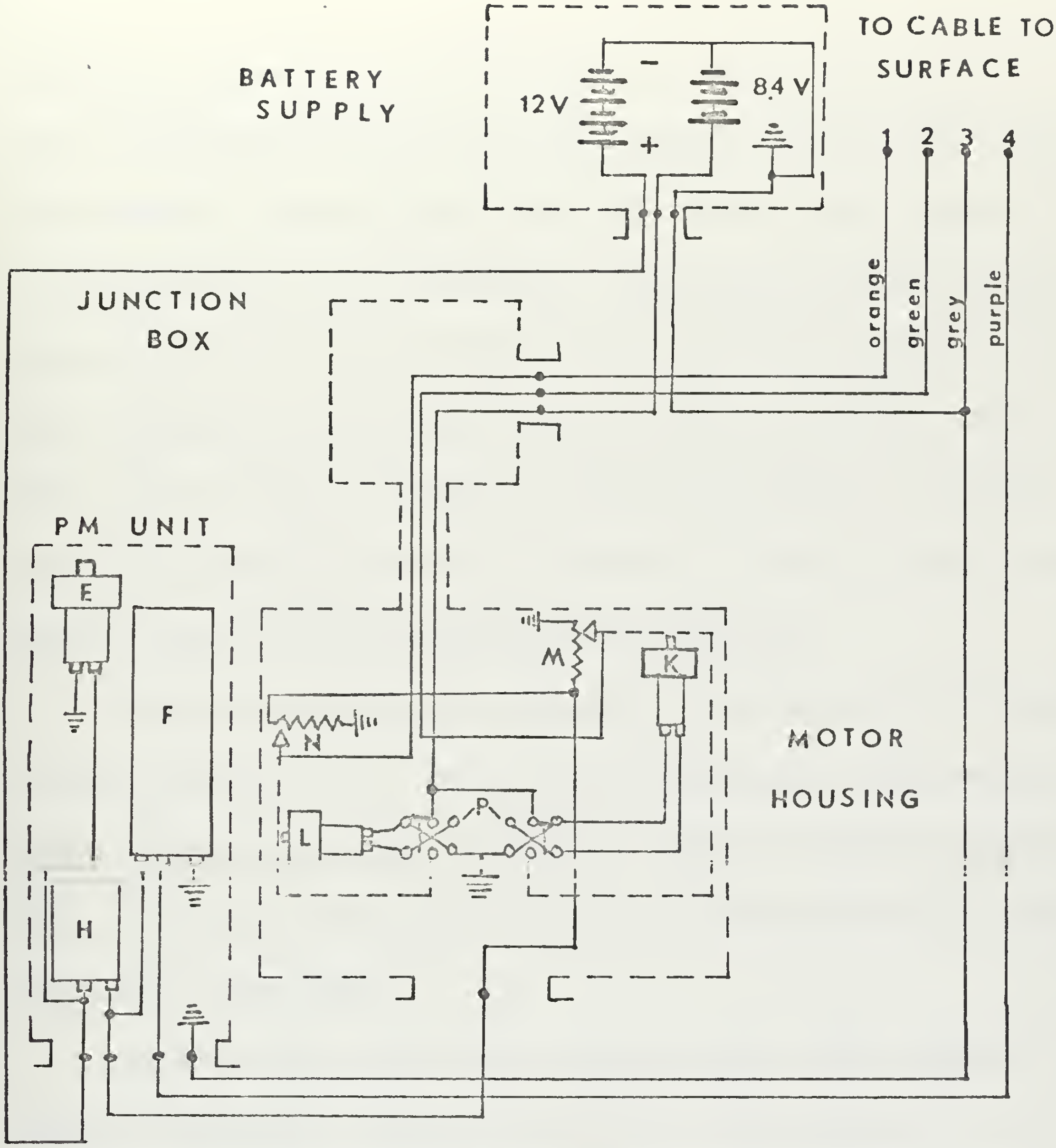


FIGURE 6. BLOCK ELECTRICAL DIAGRAM OF UNDERWATER UNIT

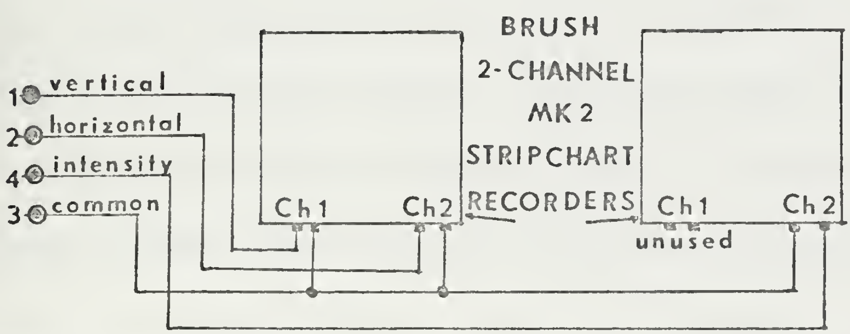


FIGURE 7. CIRCUIT DIAGRAM OF SHIPBOARD RECORDING SYSTEM
(SEE PAGE 16 FOR KEY)

allowing it to rotate 180° in a vertical plane while simultaneously rotating 360° in a horizontal plane. The optical system (Figure 5) allows light to enter through a 1/2-inch thick, clear, plate glass window within an angle of acceptance of 0.00119 steradians. Light passing through the achromatic objective lens (f = 100mm) is collimated by an inverted achromatic microscope objective (f = 3mm) before passing through the spectral wedge filter. After passing through the filter the rays are then diverged by another achromatic microscope objective, identical to the first, in order to spread the light beam over the photocathode of the detector.

A 4-inch diameter spectral wedge filter, manufactured by Optical Coating Laboratory, Inc., and having the transmission characteristics shown in Figure 8, is used. The filter is driven at 24 rpm by a small D.C. motor. Alignment of the optical system was accomplished on an optical bench with a neon laser.

The photometer circuitry was designed by Mr. Floyd Miller of the Visibility Laboratory of Scripps Institution of Oceanography, La Jolla, California. An 11-stage EMI 9524B high gain photomultiplier tube having a 0.91-inch window and S-11 response is employed. The photometer circuitry is illustrated in Figure 9, and graphs of the photomultiplier characteristics are shown in Figures 10 and 11. Operating power for the photomultiplier tube circuitry and the Burr-Brown Model 520/25, ± 15 vdc power supply maintains an output which is constant to within ± 0.25% over the input voltages used. The photometer output signal, which varies from 0 to -10 vdc, is recorded at the surface on a two-channel strip-chart recorder.

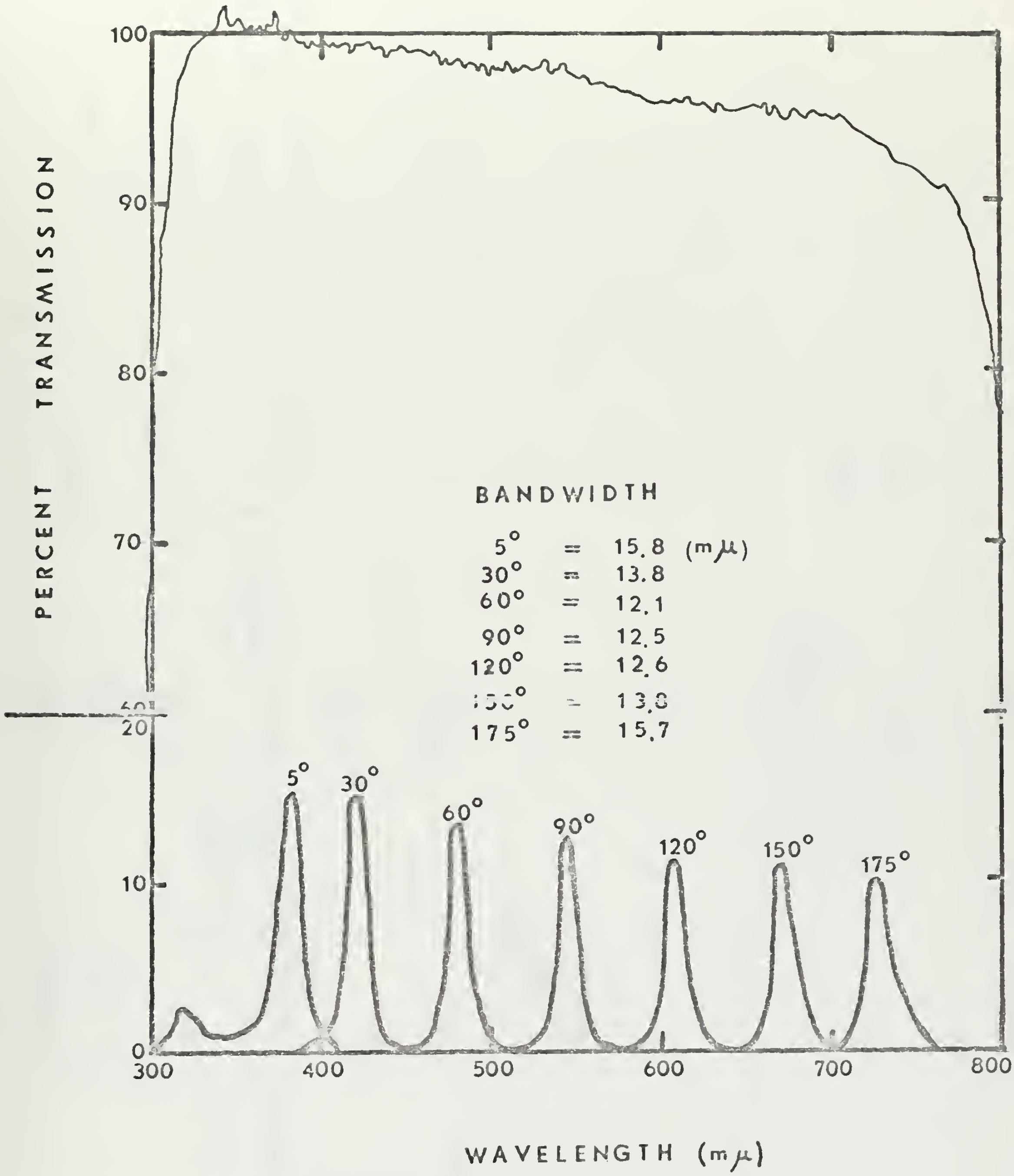


FIGURE 8. SPECTRAL WEDGE FILTER CHARACTERISTICS

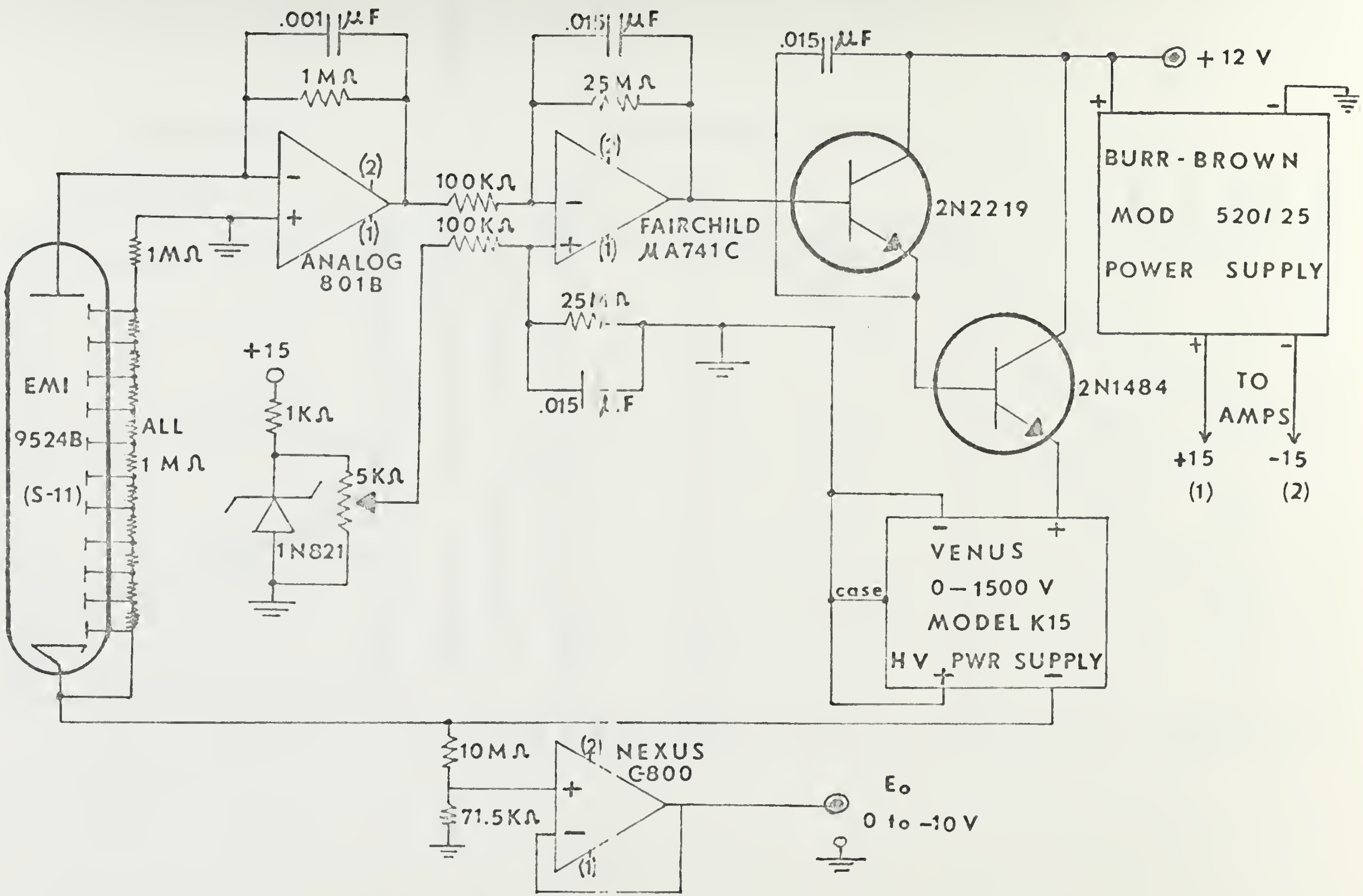


FIGURE 9. PHOTOMETER CIRCUITRY

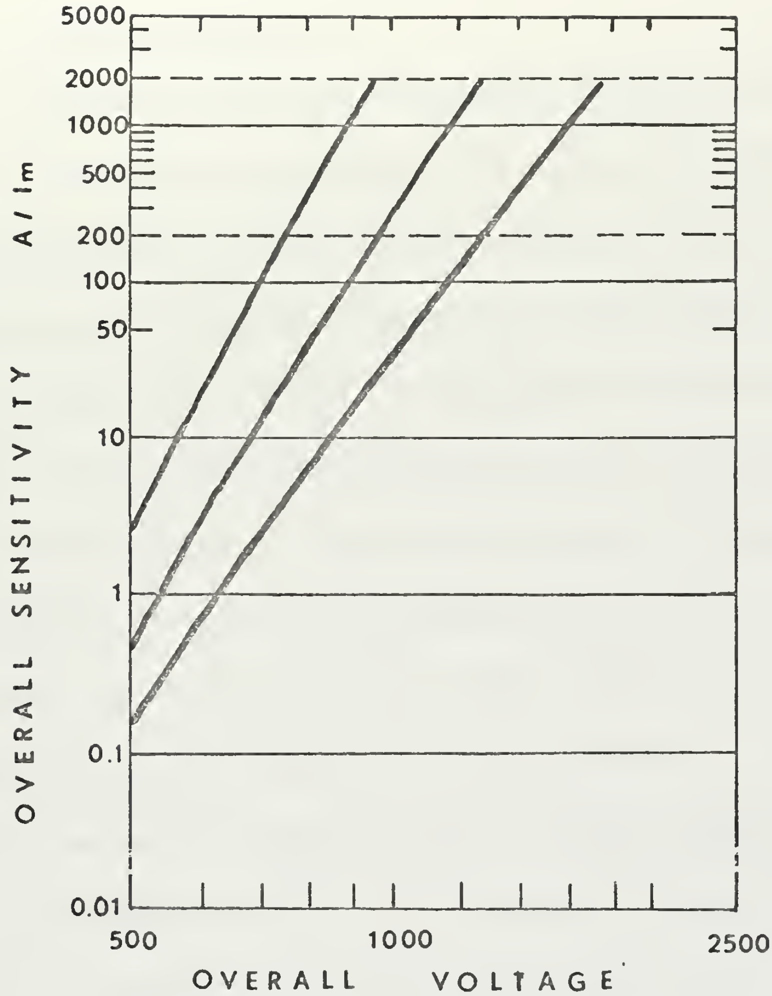


FIGURE 10. OVERALL SENSITIVITY VS OVERALL VOLTAGE

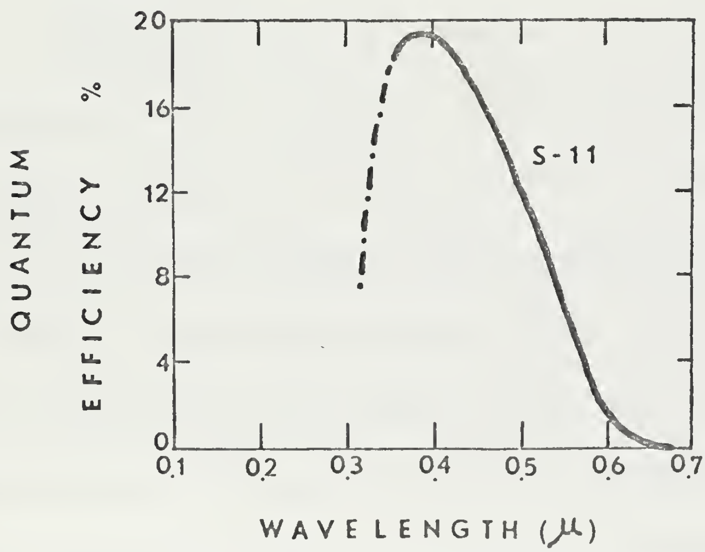


FIGURE 11. PHOTOMULTIPLIER TUBE SPECTRAL RESPONSE

2. Motor Housing Unit

The motor housing is constructed of stainless steel periscope stock having an internal diameter of 6 1/2 inches, a length of 8 inches, and 1/2-inch walls. The end plates are made of 3/4-inch aluminum. Brass bearings provide lateral support for the rotating stainless steel shafts. O-rings seal the shafts and end plates of the unit from the sea water. Inside the motor housing (Figure 4) are two reversible D. C. motors, azimuth (ϕ) and vertical (θ) angle potentiometers, and reversing switches, which provide for continuous photometer rotation through 180° in a vertical plane and 360° in a horizontal plane. The ϕ-shaft motor is driven at 5.33 degrees/second by a small 35 vdc motor while the θ-shaft is driven by another motor at 13.4 degrees/second. Angular rotations are measured with two potentiometers having 0.5% linearity, the outputs of which are displayed on a shipboard two-channel strip-chart recorder.

3. Junction Box

The junction box is constructed of 1/2-inch thick aluminum tubing having an internal diameter of 4 inches and length of 5 inches. The end plates are made of 3/4-inch aluminum. A hollow stainless steel shaft connects the motor housing to the junction box and provides a passage for electrical wires between the two units. To the junction box is attached a 20-inch by 19-inch rudder to stabilize the meter with respect to a vertical plane. The signals from the two angle potentiometers are brought out through two single-pin underwater connectors located at one end of the cylinder.

4. Battery Supply

The battery housing is 8 inches long with 3/4-inch end plates and is made of the same periscope stock used for the motor housing. Nickel-cadmium cells having 4 ampere-hour capacity are used in the battery packages. One package contains 10 cells (12v) and provides power to operate the spectral wedge filter motor, the photometer circuitry, and the angle potentiometers. The other package contains 7 cells (8.4 v) and provides operating power to the ϕ and θ drive shafts.

B. CALIBRATION

1. Azimuth and Vertical Angles

A Lietz three-arm vernier protractor and a Brush two-channel strip-chart recorder were used to measure chart line deflection as a function of angular rotation in the vertical and horizontal planes. Calibration curves for azimuth and vertical angles are shown in Figures 12, 13, and 14.

2. Spectral Wedge Filter

Narrow-band interference filters were used with sodium and mercury arc lamps in the calibration of the spectral wedge filter for wavelengths as a function of angle of rotation. The only sodium line used was that at 568.82 nm, while the mercury lines used were at 365.01, 404.66, 435.84, 546.10, 576.96 and 690.72 nm. Figure 15 gives transmission wavelength of the wedge filter as a function of angle of rotation.

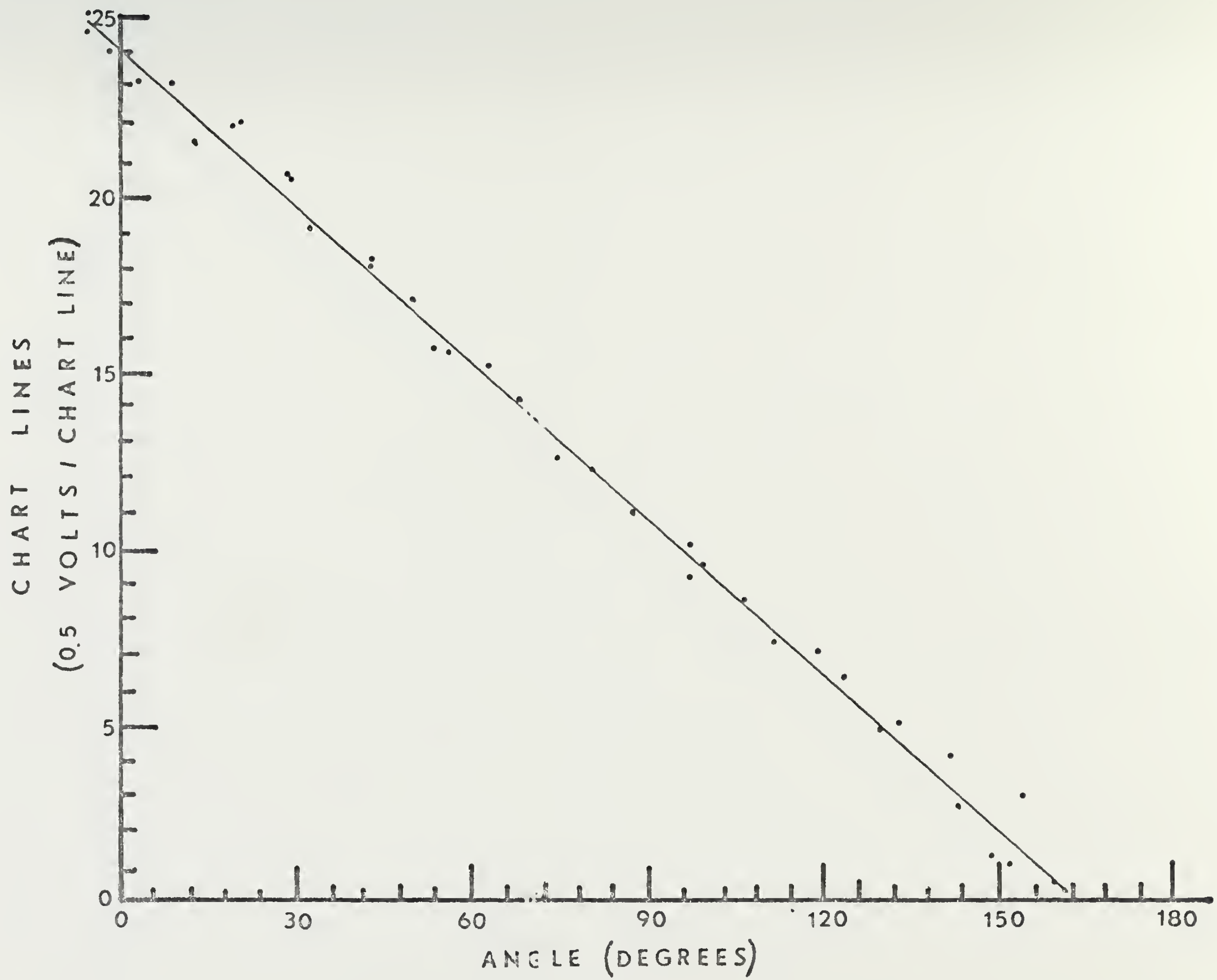


FIGURE 12. VERTICAL ANGLE CALIBRATION CURVE IN DOWNWARD DIRECTION

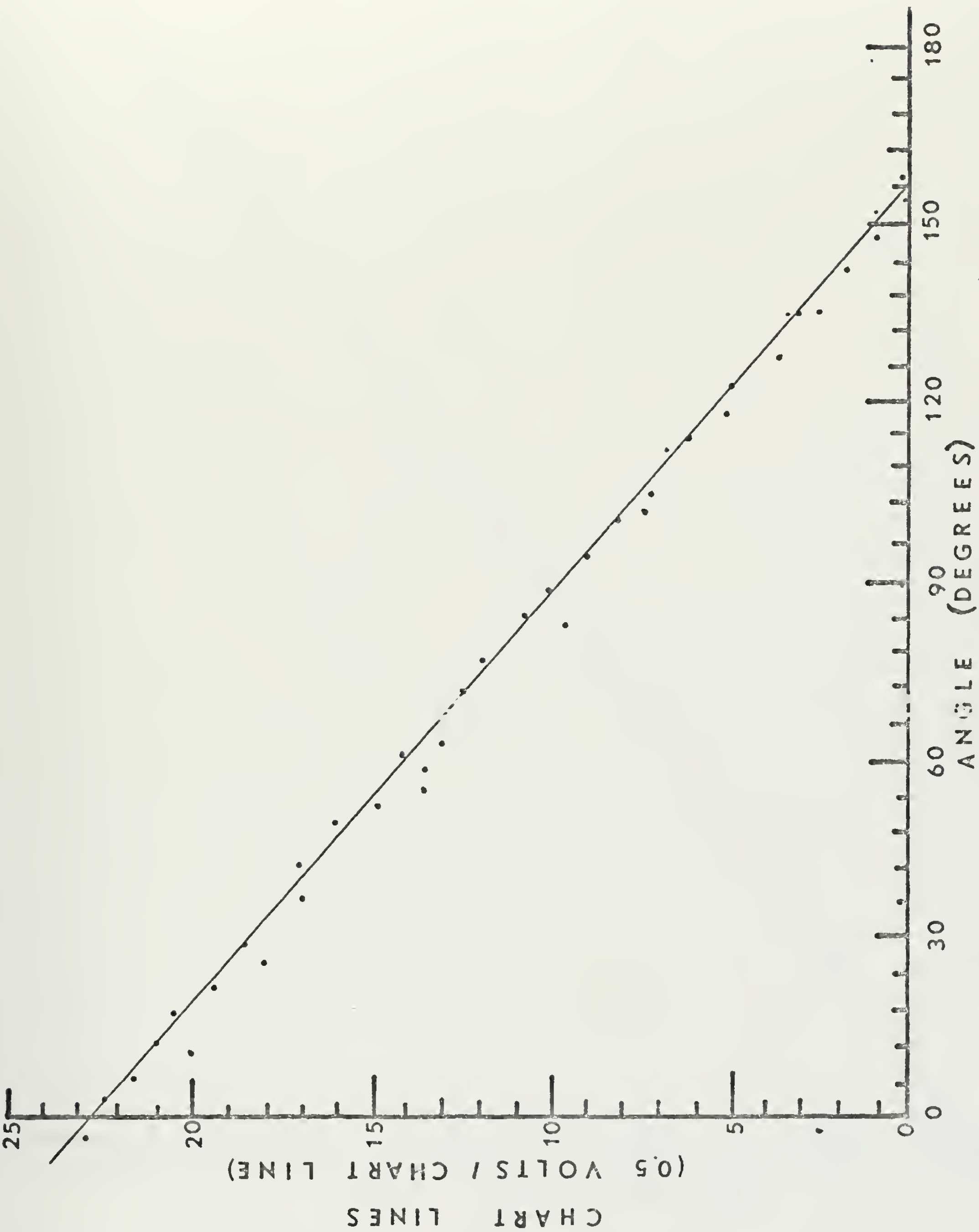


FIGURE 13. VERTICAL ANGLE CALIBRATION CURVE IN UPWARD DIRECTION

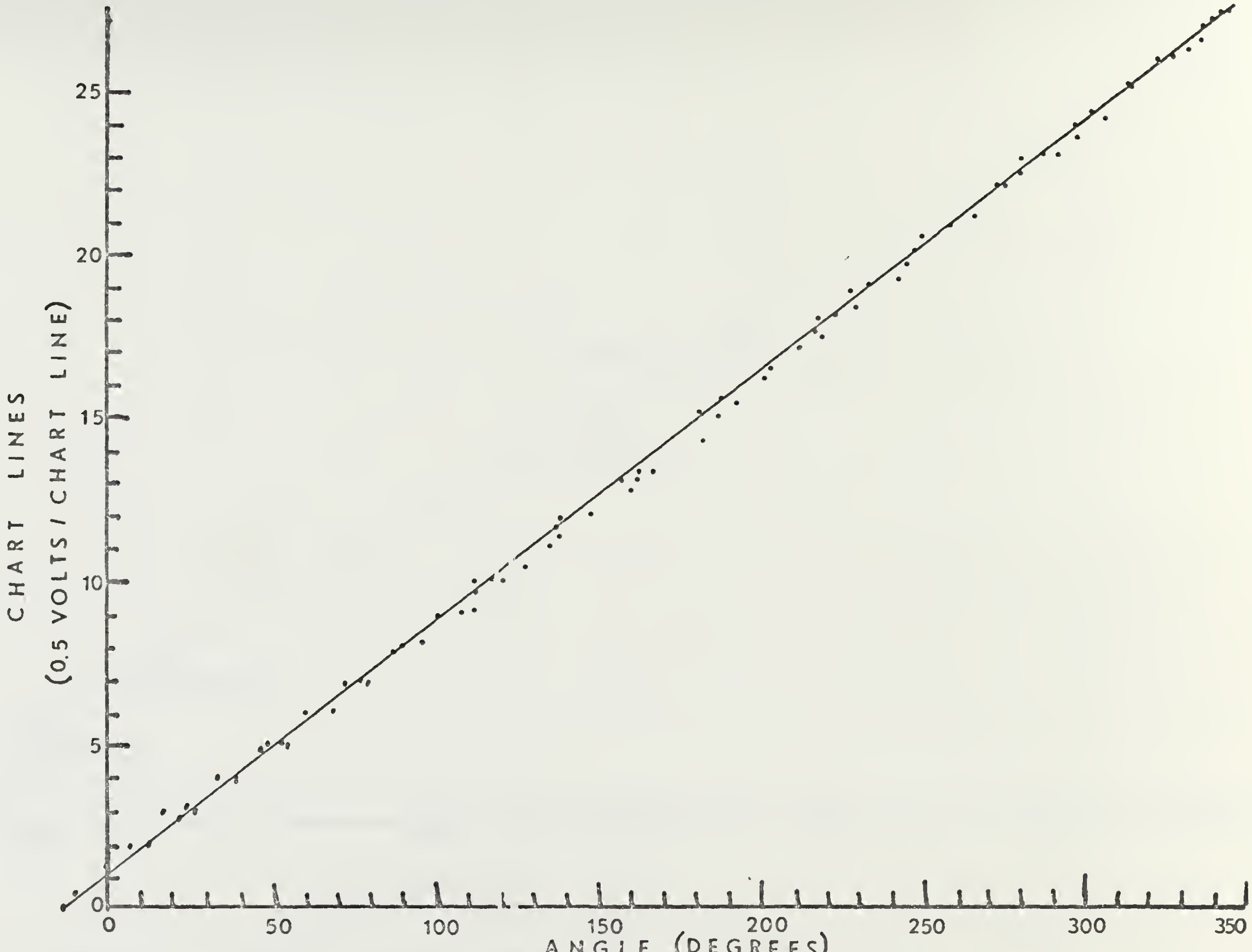


FIGURE 14. AZIMUTH ANGLE CALIBRATION CURVE

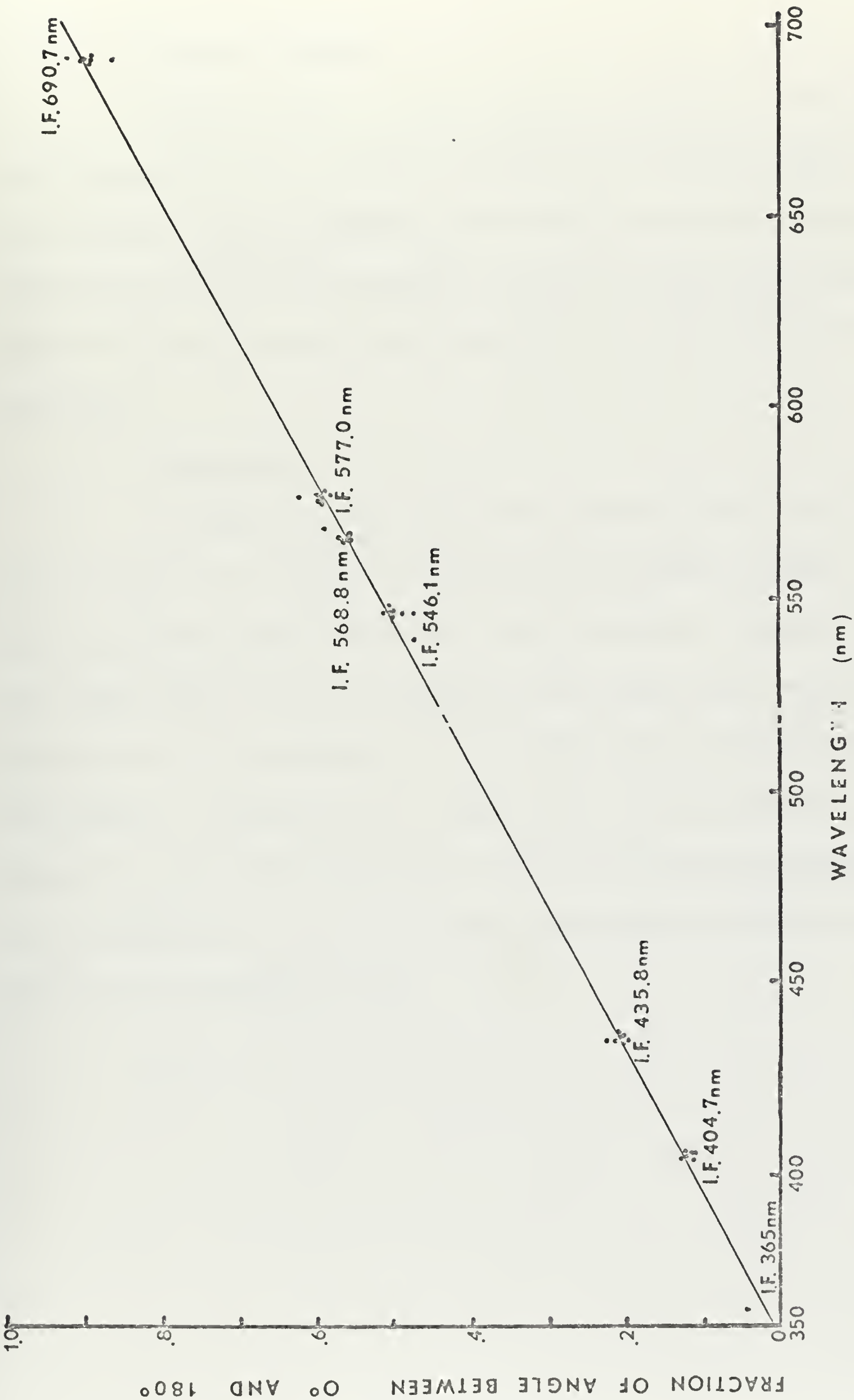


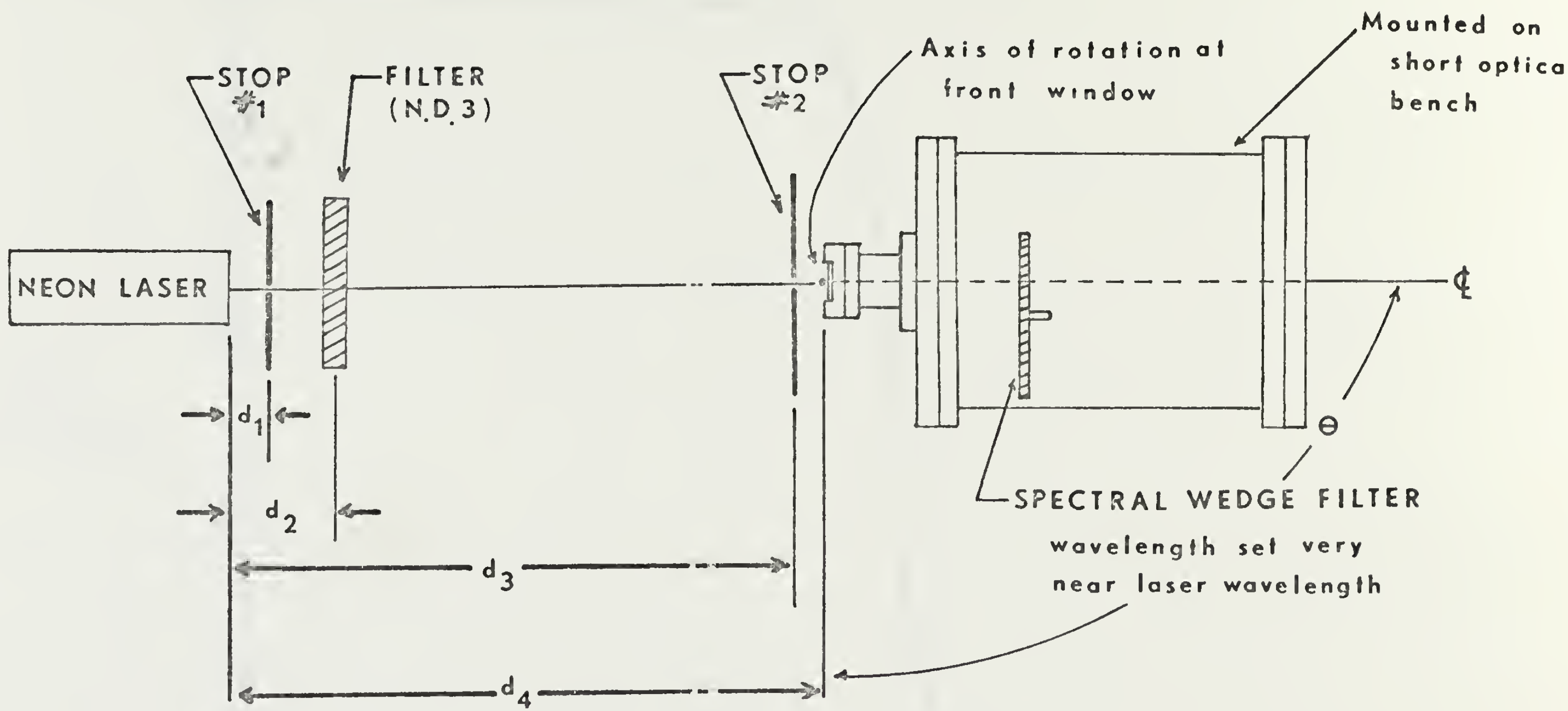
FIGURE 15. SPECTRAL WEDGE FILTER ROTATION CALIBRATION CURVE

3. Acceptance Angle

A He-Ne laser (λ = 632.8 nm) was used with a neutral density filter to measure the acceptance angle of the photometer (Figure 16). The photometer unit was rotated at small angular increments, and radiance (chart line deflection) was recorded as a function of half-angle rotation (Figure 17). The acceptance angle was determined to be 2° 14' or 0.00119 steradians.

4. Photometer

A Gamma Scientific Model 220 calibrated optical source system with a Model 220-1A radiance head was used in absolute intensity calibration of the photometer (Figure 18). The Model 220-1A radiance head has a light output of 100 ± 2 footlamberts, color temperature equal to 2854 ± 50°K, and a uniformity of ± 1.5% within the 3-inch diameter luminous surface. The Model 220-1A output curve is shown in Figure 19. Wratten No. 96 neutral density filters were used in density increments of 0.1 to calibrate the photometer in terms of intensity and wavelength in absolute units (Figures 32 - 44).



DISTANCES: $d_1 = 180$ mm
$d_2 = 225$ mm
$d_3 = 528$ mm
$d_4 = 585$ mm

DIAMETER OF STOPS: #1 = 1.5 mm
#2 = 0.5 mm

FIGURE 16. ACCEPTANCE ANGLE CALIBRATION ARRANGEMENT

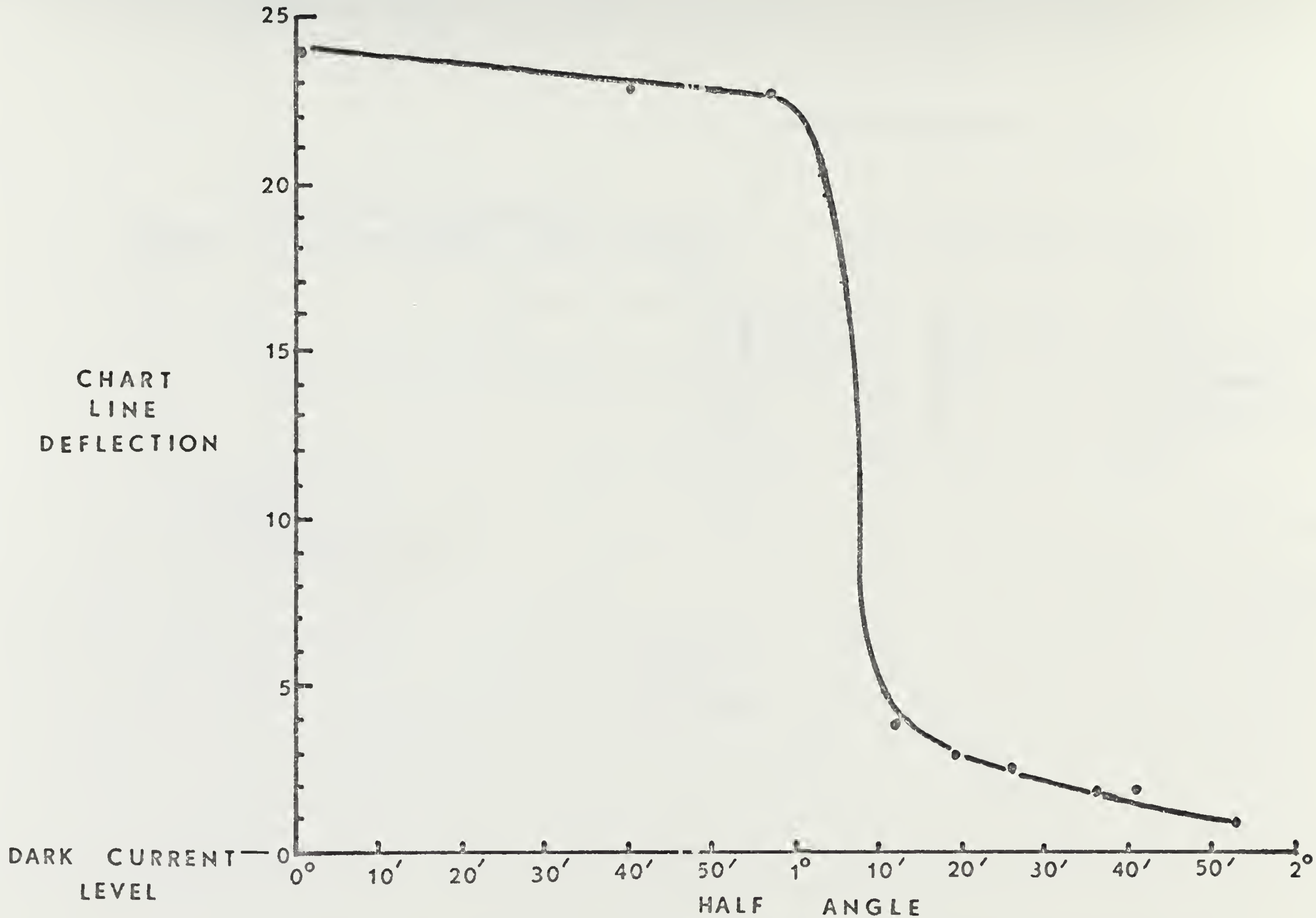


FIGURE 17. ACCEPTANCE ANGLE CALIBRATION CURVE

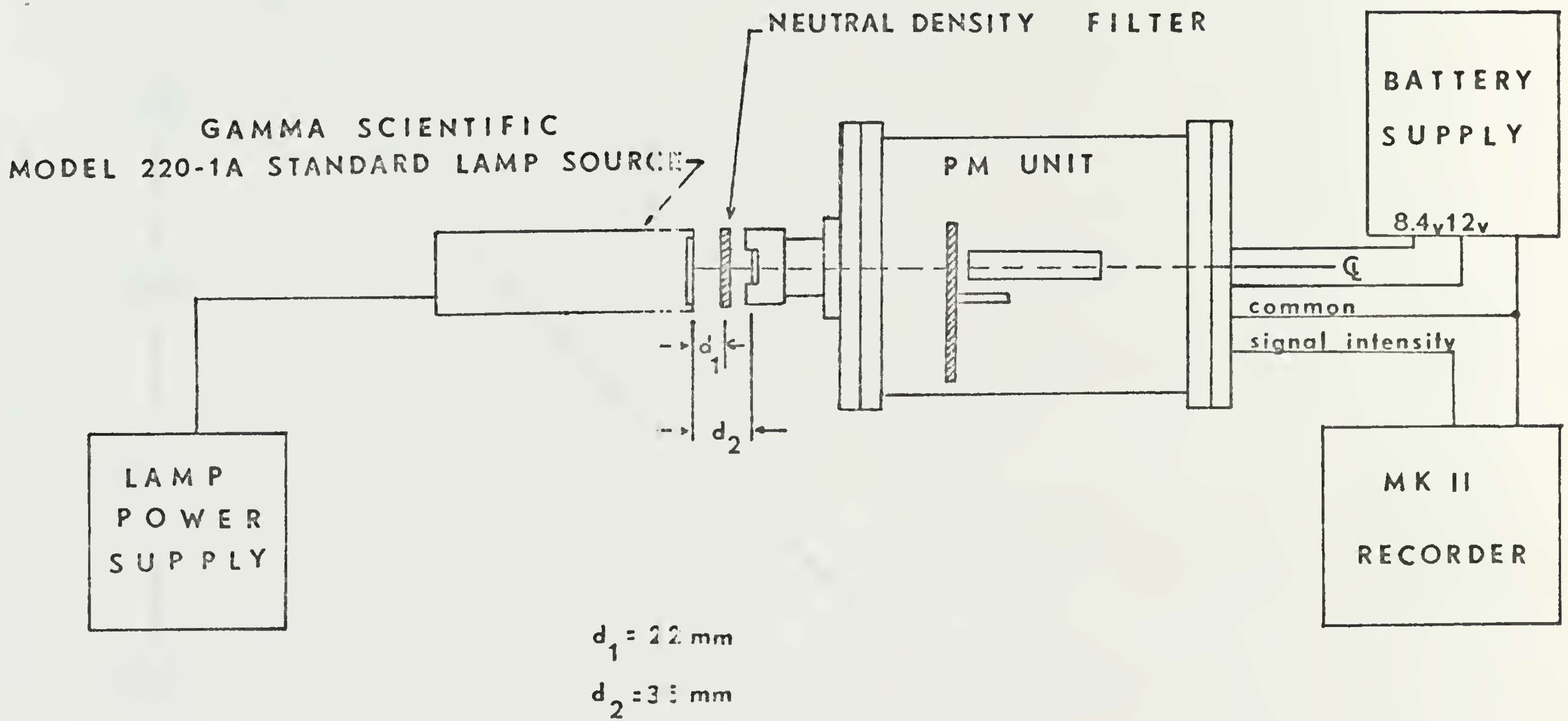


FIGURE 18. SYSTEM CALIBRATION ARRANGEMENT

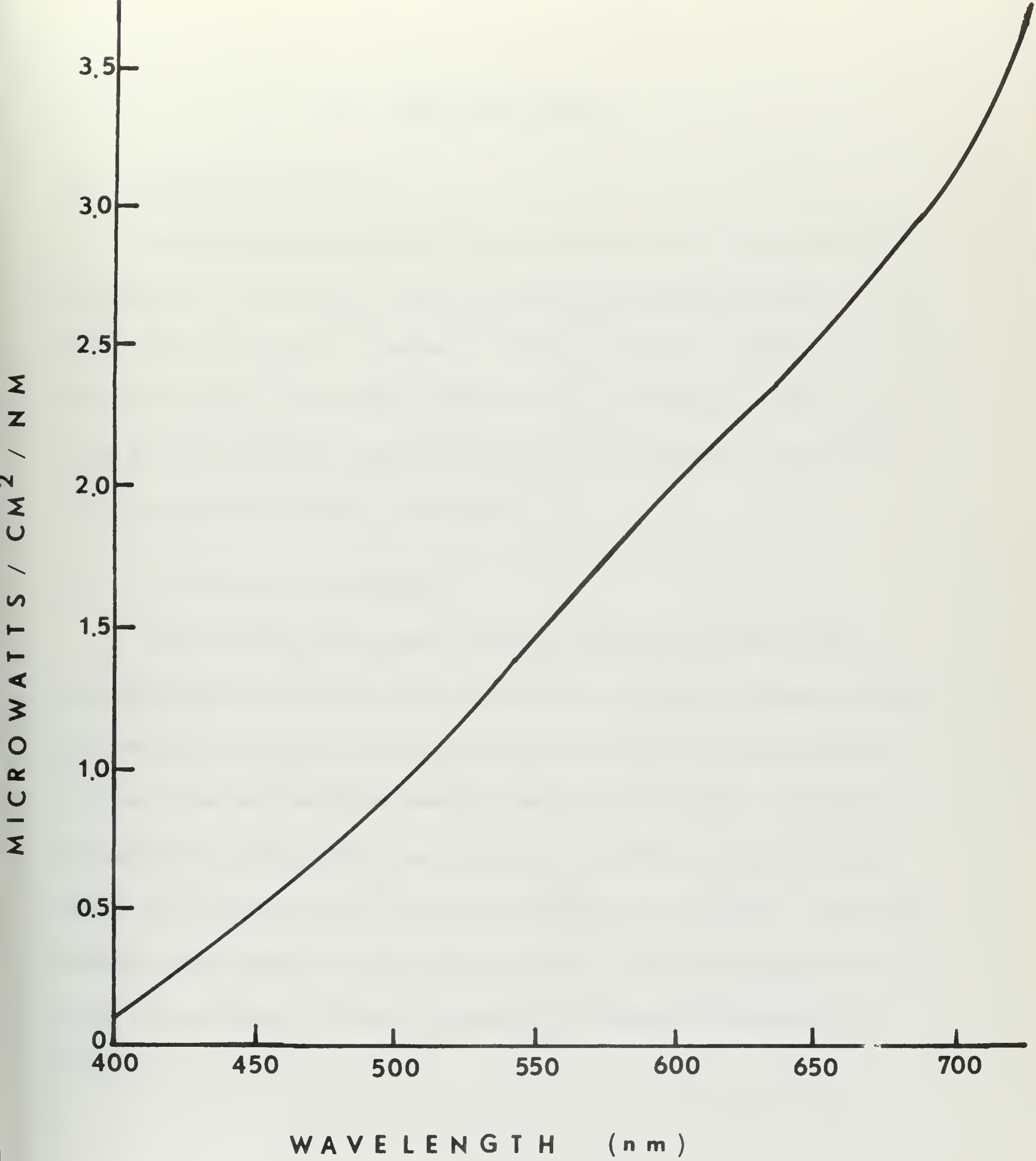


FIGURE 19. CALIBRATION CURVE FOR STANDARD LAMP

III. DATA COLLECTION

A. STATION LOCATIONS

During July 1971 spectral radiance measurements were made in Monterey Bay, California, aboard the Naval Postgraduate School's 63-foot boat. The two stations occupied are shown in Figure 1. Station positions were determined every fifteen minutes by visual bearings. These, along with the time, weather, altitude of the sun, and azimuth of the sun for each station are presented in Appendix C.

B. OPERATIONAL PROCEDURES

At each station the spectral radiance meter was lowered to the desired depths by means of a four-conductor, externally armored, electrical cable and allowed to rotate continuously through several rotational cycles in the horizontal and vertical planes at each depth. Continuous measurements of the angular and spectral distribution of submarine daylight were recorded on two dual-channel strip-chart recorders. Instrument depths were indicated by meter wheel readings. The wire angle for each case was negligible. Typical recordings of raw data are presented in Figure 20.

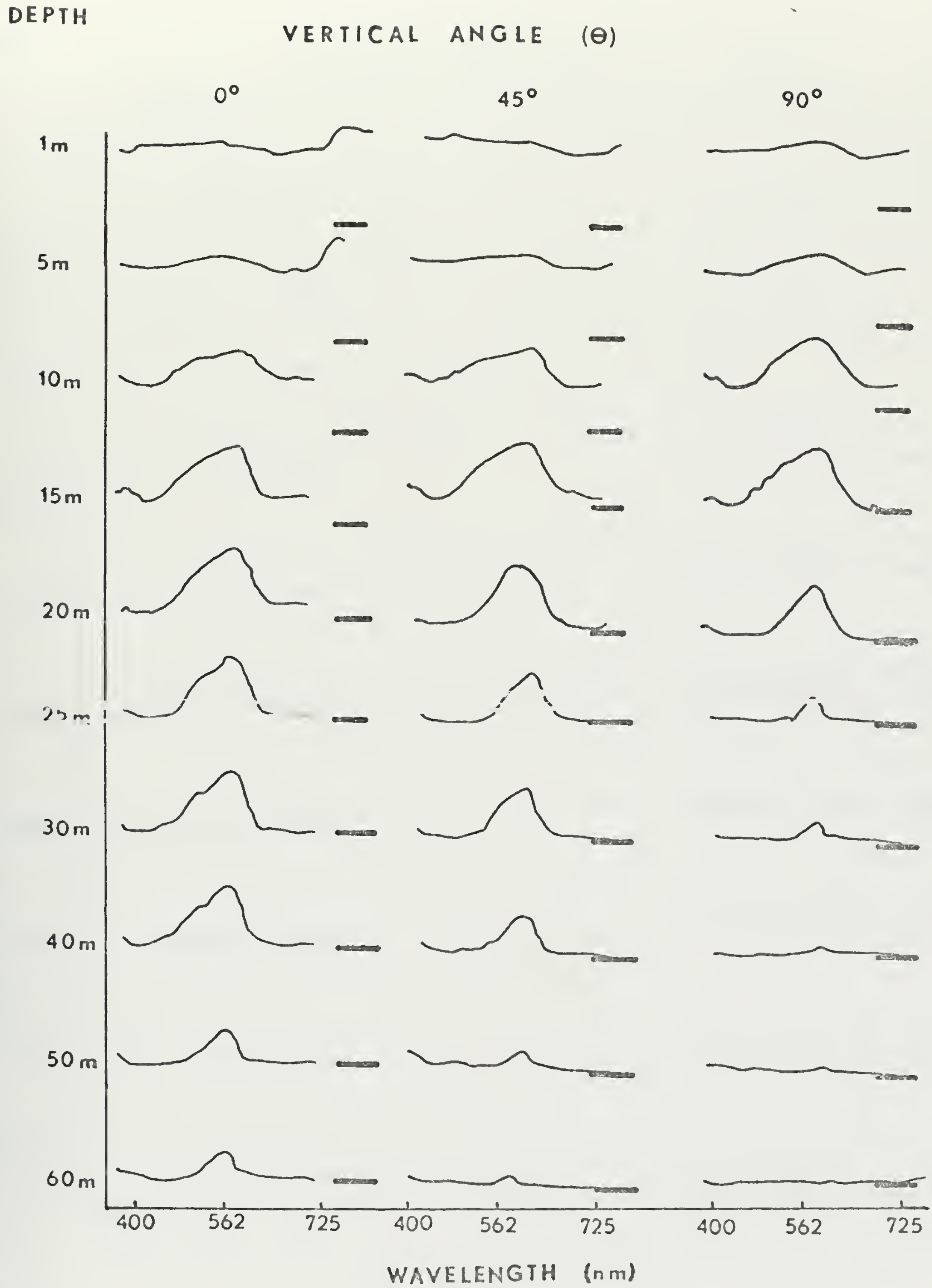
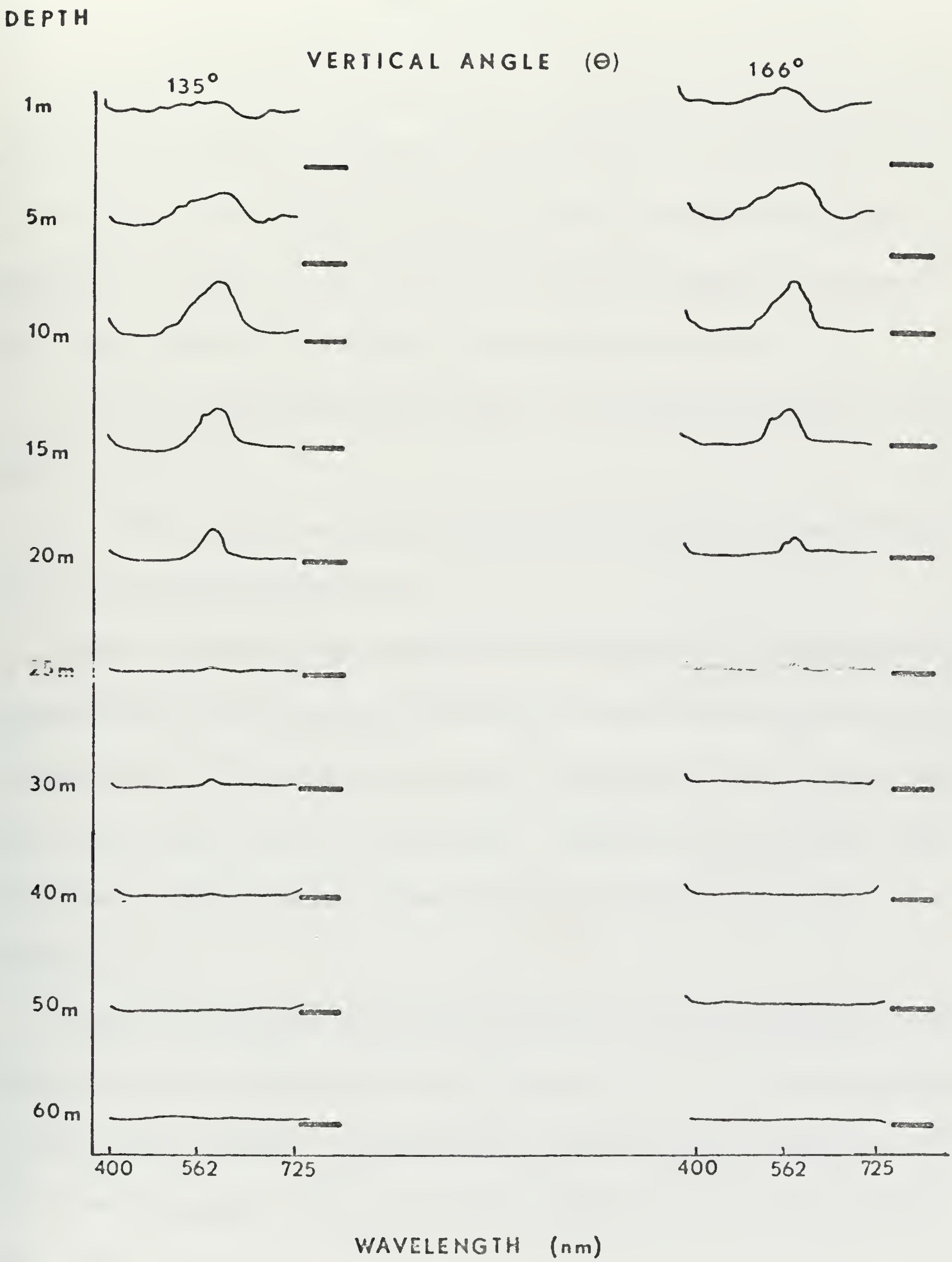


FIGURE 20. UNCORRECTED SPECTRAL RADIANCE VARIATION WITH DEPTH AT $\phi = 0$. THE DARK CURRENT REFERENCE LEVEL IS INDICATED TO THE RIGHT OF EACH CURVE.


DEPTH
VERTICAL ANGLE (Θ)
135°
166°
1m
5m
10m
15m
20m
25m
30m
40m
50m
60m
400
562
725
400
562
725
WAVELENGTH (nm)

IV. DATA ANALYSIS

A manual analysis of the uncorrected strip-chart records (Figure 21) was made, and values of absolute spectral radiance are shown in Appendix C. Using these data graphs of spectral radiance variation with depth were plotted for $\phi = 0$ and $\theta = 0, 45, 90, 135,$ and 166 degrees (Figures 22-31). In the analysis the following assumptions were used:

(1) The maximum intensity of light in the horizontal plane is in the azimuth of the sun.

(2) The vertical and horizontal axes of the meter remained stationary at a given depth during scans.

Angular rotation in the vertical and horizontal planes was determined by measuring vertical chart line deflections on the recorder output and then entering Figures 12-14 with these values to obtain the azimuth and vertical angle of a selected point of observation. Observed azimuth angles were expressed in relative angles to the direction of the sun by applying assumption (1).

Since the spectral wedge filter revolves at a constant angular speed, wavelength can be expressed in terms of time, $\lambda = \lambda(t)$, and recorded on the strip-chart recorder. Wavelength was then determined from the ratio of the partial angular rotation to the total angular rotation of the spectral wedge filter (Figure 15).

As shown in Figure 21, the spectral output shows the radiance of unfiltered light (high light levels) followed by spectral radiance (low light

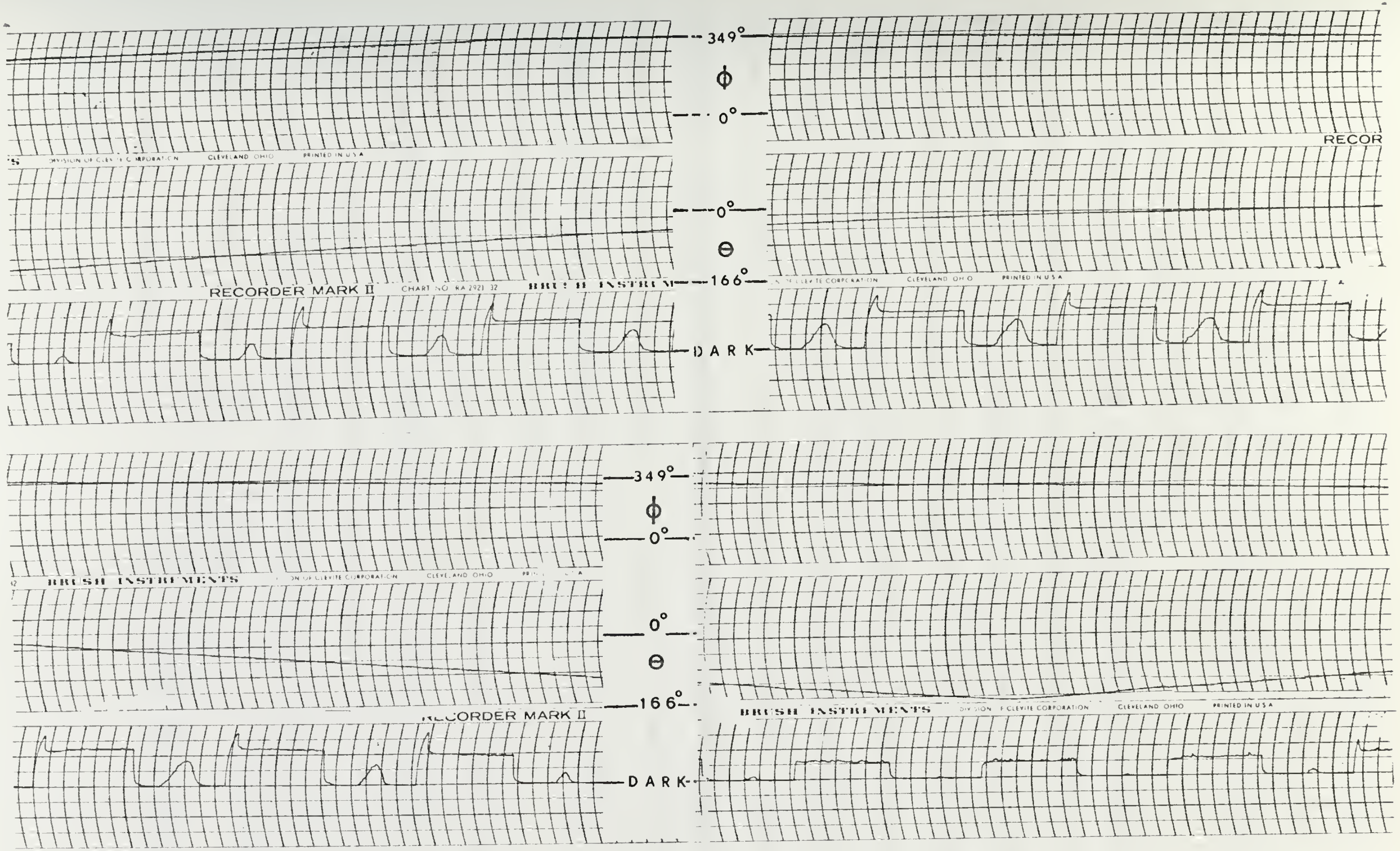


FIGURE 21. SAMPLE OF SPECTRAL RADIANCE OUTPUT

levels) from 350 to 725 nm, which is followed by unfiltered light. The end points of 0° and 180° on the spectral wedge filter are shown clearly as the sharp vertical lines. Overshooting of the curve is due to the rapid transition from filtered to unfiltered light.

Radiance was determined for the angle of acceptance of the meter by using the nomograms shown in Figures 32-44 (Appendix B). Measurements of vertical chart line deflections of the recorder output signal were converted to a corresponding intensity expressed by the neutral density filter used in the photometer system calibration for a selected wavelength band (Curve A). Radiance for the given wavelength band was then determined by using Curve B. Curve B represents a plot of the values of irradiance (Figure 19) of the standard lamp source over a 25 nm wavelength band as a function of transmittance. To express the spectral radiance in terms of $w/cm^2/sr$, a multiplying factor of 838.22 was applied to account for the acceptance angle of 0.00119 steradians.

When these figures were prepared the different Fresnel light reflection coefficients at normal incidence between the observational case (water and glass) and the calibration case (air and glass) were not taken into account. Thus the radiance values presented in the figures are all high by a constant factor, $\frac{n_{air}}{n_{sw}} \cdot \left(\frac{n_{glass} + n_{sw}}{n_{glass} + n_{air}} \right)^2$, where the n's are the indices of refraction for air, sea water, and the glass window used for the meter.

Figures 22-31 (Appendix A), which are plots of the spectral radiance distribution with depth, $\theta = 0, 45, 90, 135$, and 166 degrees at $\phi = 0$ degrees, show spectral peaks at about 570 nm. Peaks at about this wavelength were observed at Lake San Vicente by Tyler and Smith [1970].

The figures also show an apparent high radiance in the 400-450 nm region which is probably instrumental in nature and due to the relatively slow recovery time of the photometer when subjected to sudden large steps in light intensity during filter rotation from unfiltered to filtered light. A similar feature is observed following the overshooting in the curves from filtered to unfiltered light (Figure 21).

In many of the figures the plots of spectral radiance at $\theta = 0$ and 45 degrees for shallow depths were not drawn because the radiant intensity in these regions exceeded the limitations of the standard lamp used in the photometer calibration.

V. CONCLUSIONS

A spectral radiance meter having a spectral wedge filter was designed, constructed and used to obtain measurements of spectral radiance with depth at two stations in southern Monterey Bay, California, on an overcast day. Variations of the spectral radiance distribution with depth were plotted for the following vertical angles (θ): 0, 45, 90, 135, and 166 degrees. The azimuth angle (ϕ) was zero degrees with respect to the sun. The results seem reasonable in all cases.

A rotating spectral wedge filter is a practical means of obtaining a spectral radiance response.

The manner in which data was recorded imposed severe limitations on analysis. In future studies the radiance meter will be wired directly to the multiplexer and A-to-D converter of a PDP-8/S computer. This will greatly simplify the problem of data handling.

It is recommended that horizontal and vertical reference sensors be installed to improve the accuracy of the results.

Its size and shape make the instrument convenient for performing frequent observations, and future studies with this instrument are planned. In future research, simultaneous measurements of transmissivity, scattering and spectral radiance will be made in Monterey Bay to provide sufficient empirical data to test the theoretical laws of light distribution in the sea. In addition, the meter will be used in base-line studies of California coastal waters.

APPENDIX A

Figures of Spectral Radiance Distribution with Depth at $\phi = 0°$ and $\theta = 0$, 45, 90, 135, and 166° for Stations 1 and 2.

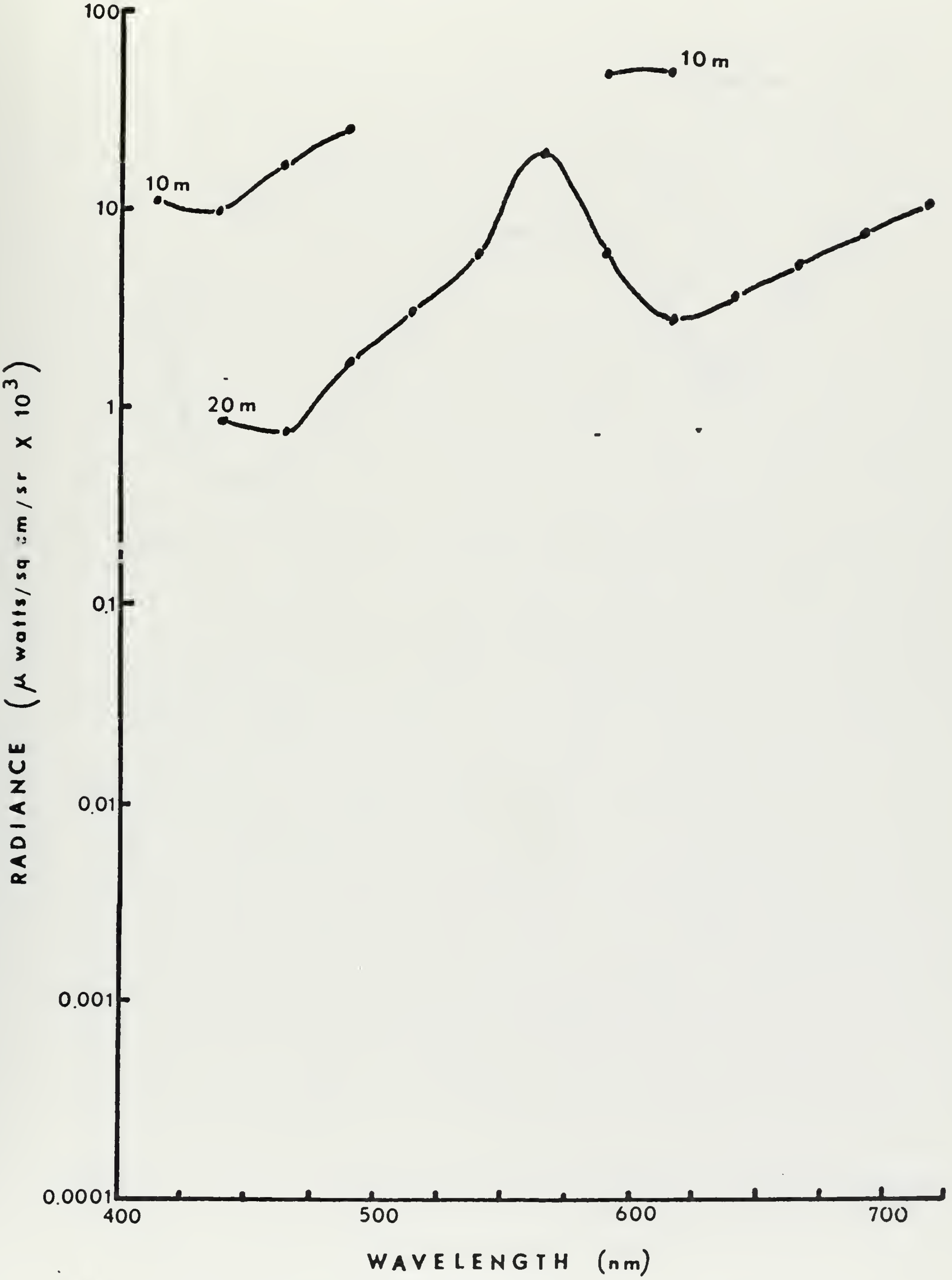


FIGURE 22. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 0°$ AND $\phi = 0°$, STA 1

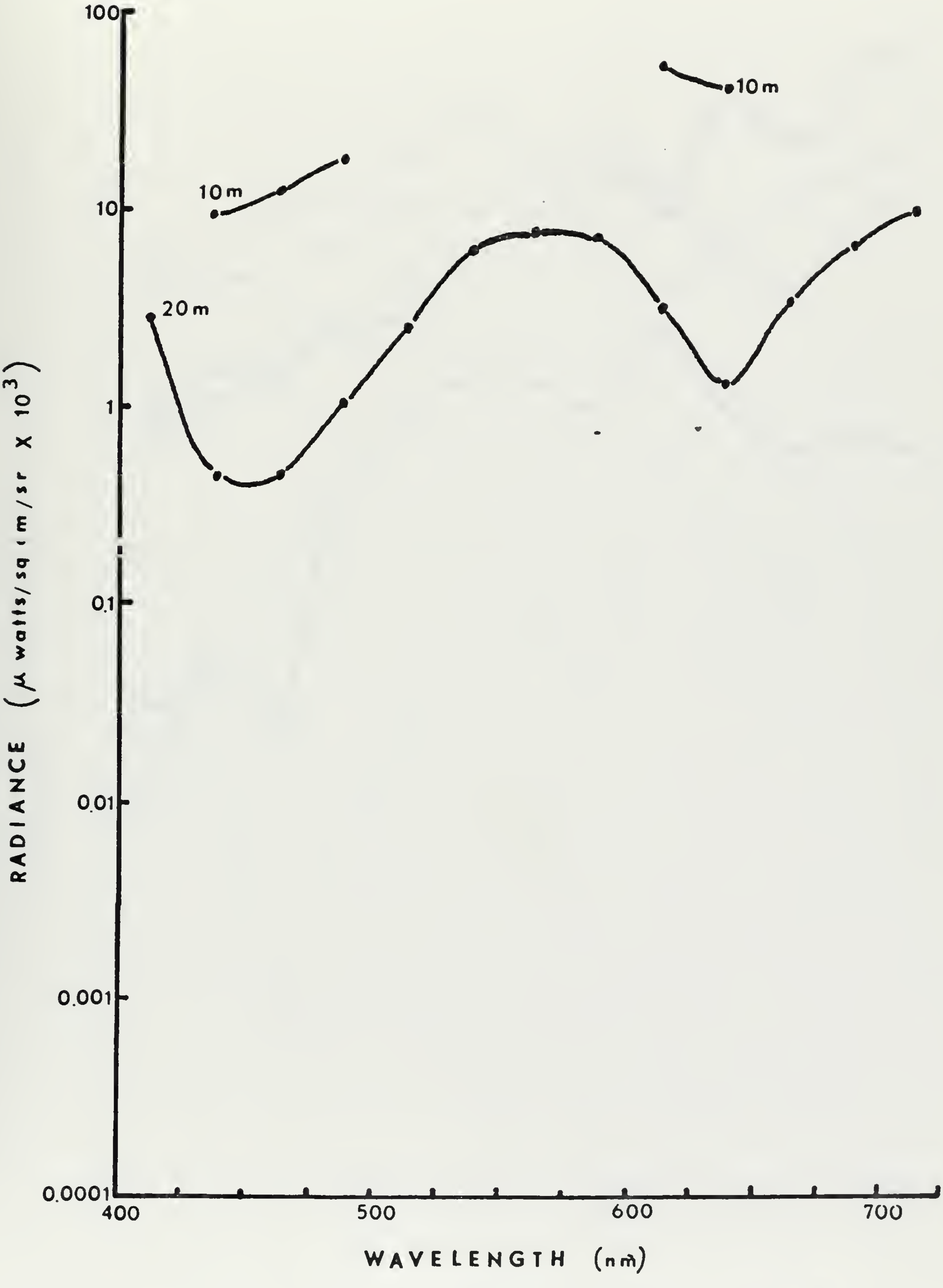


FIGURE 23. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 45°$ AND $\phi = 0°$, STA 1

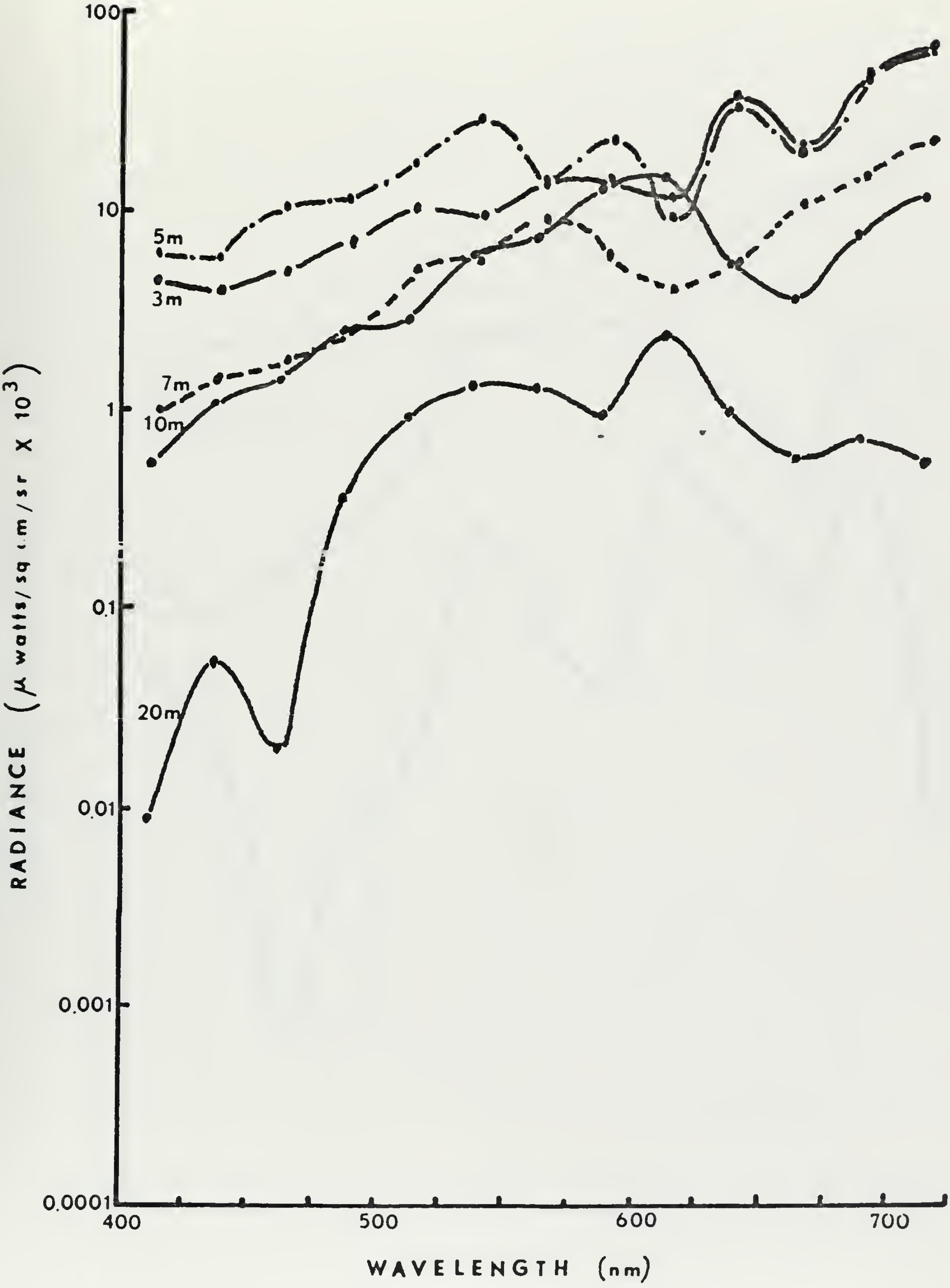


FIGURE 24. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 90°$ AND $\phi = 0°$, STA 1

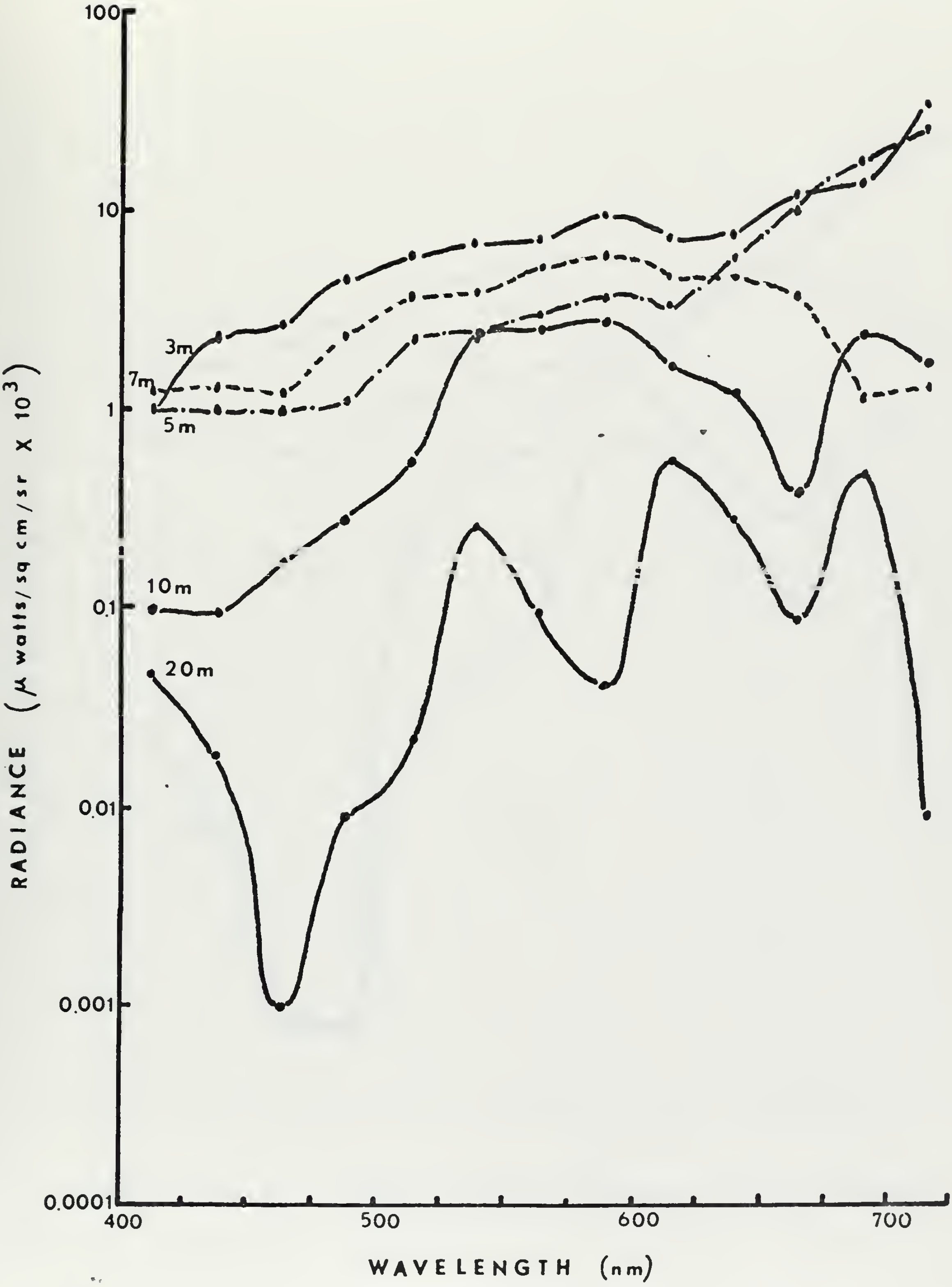


FIGURE 25. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 135°$ AND $\phi = 0°$, STA 1

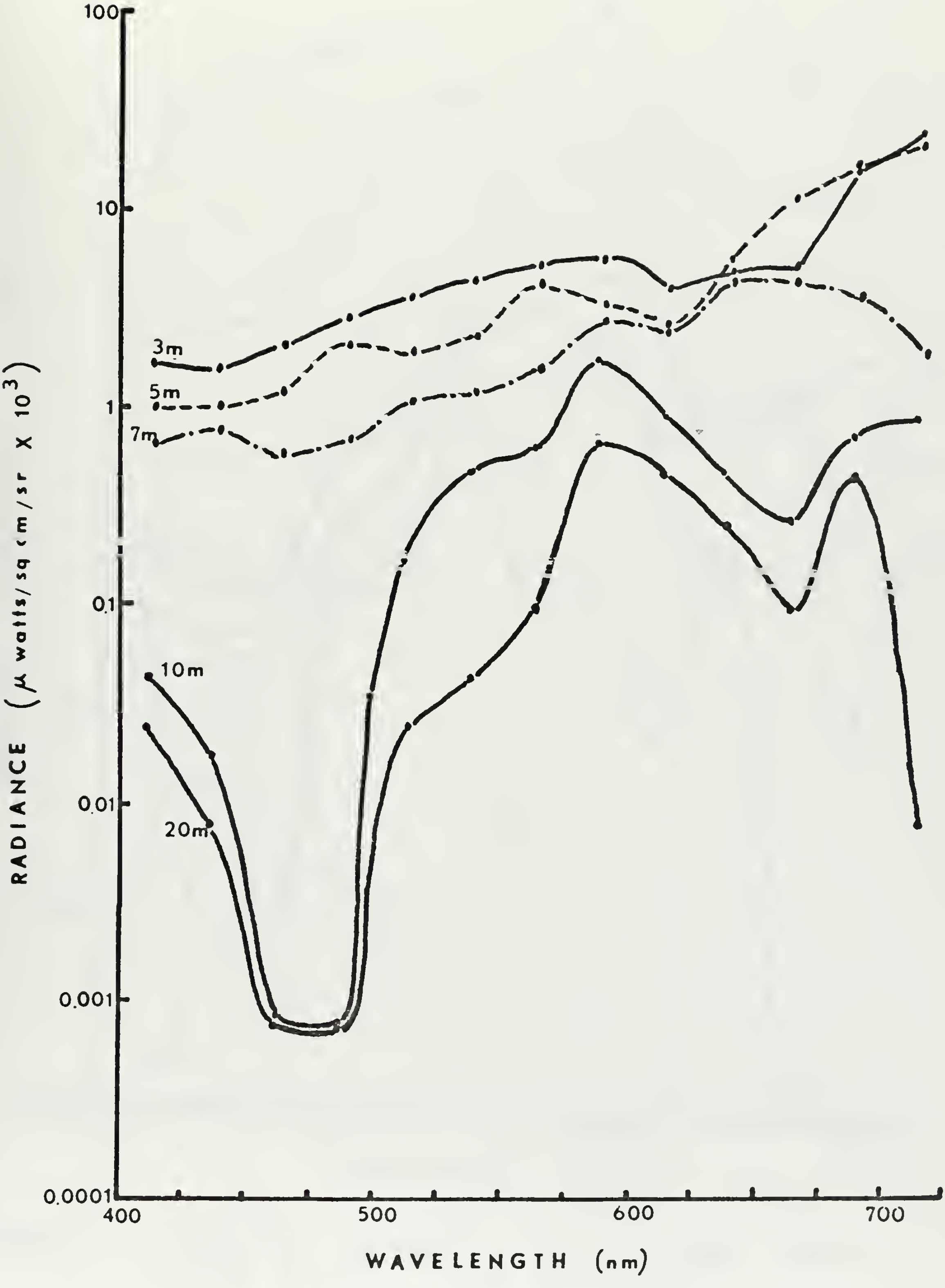


FIGURE 26. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 166°$ AND $\phi = 0°$, STA 1

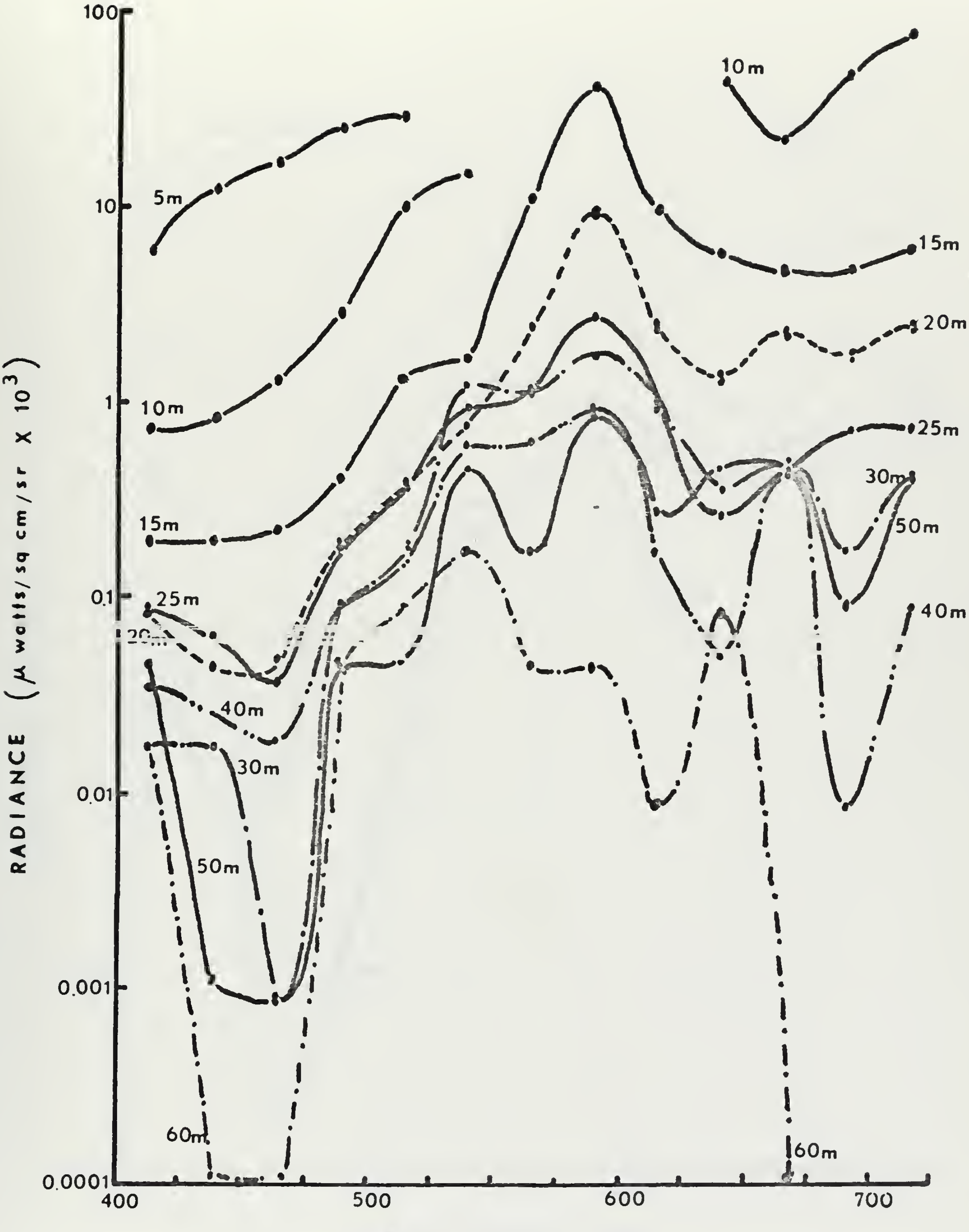


FIGURE 27. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 0°$ AND $\phi = 0°$, STA 2

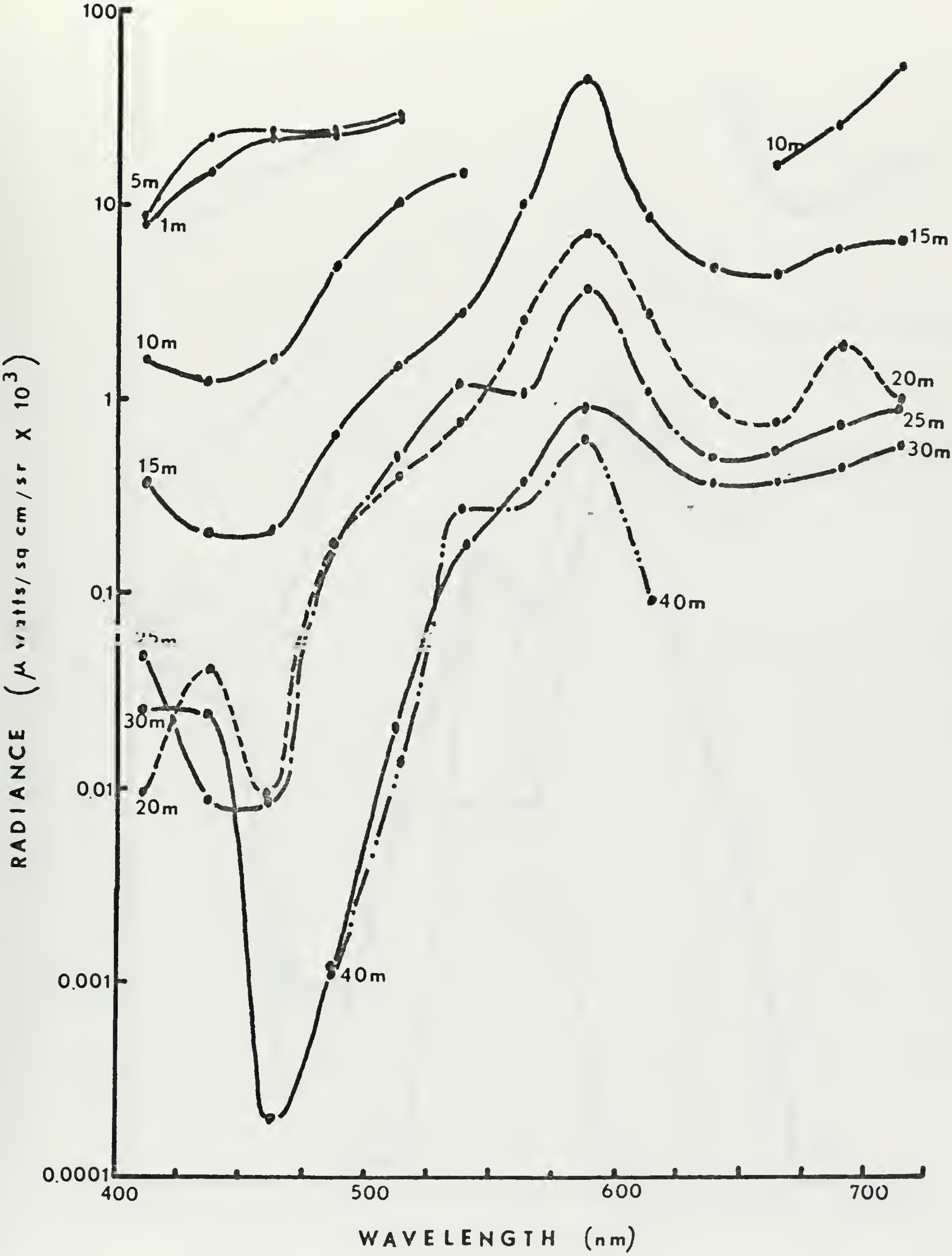


FIGURE 28. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 45°$ AND $\phi = 0°$, STA 2.

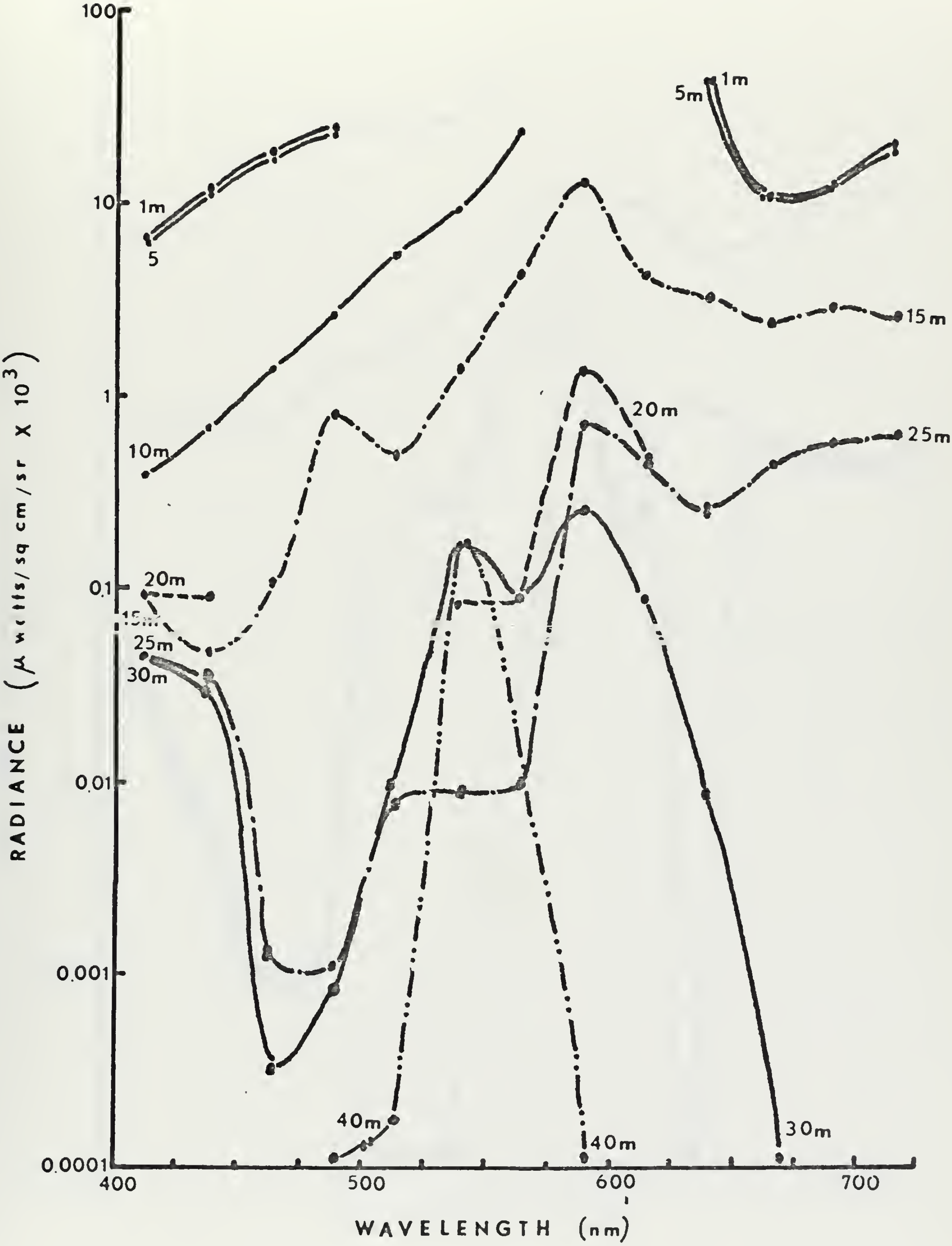


FIGURE 29. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT Θ= 90° AND φ = 0°, STA 2

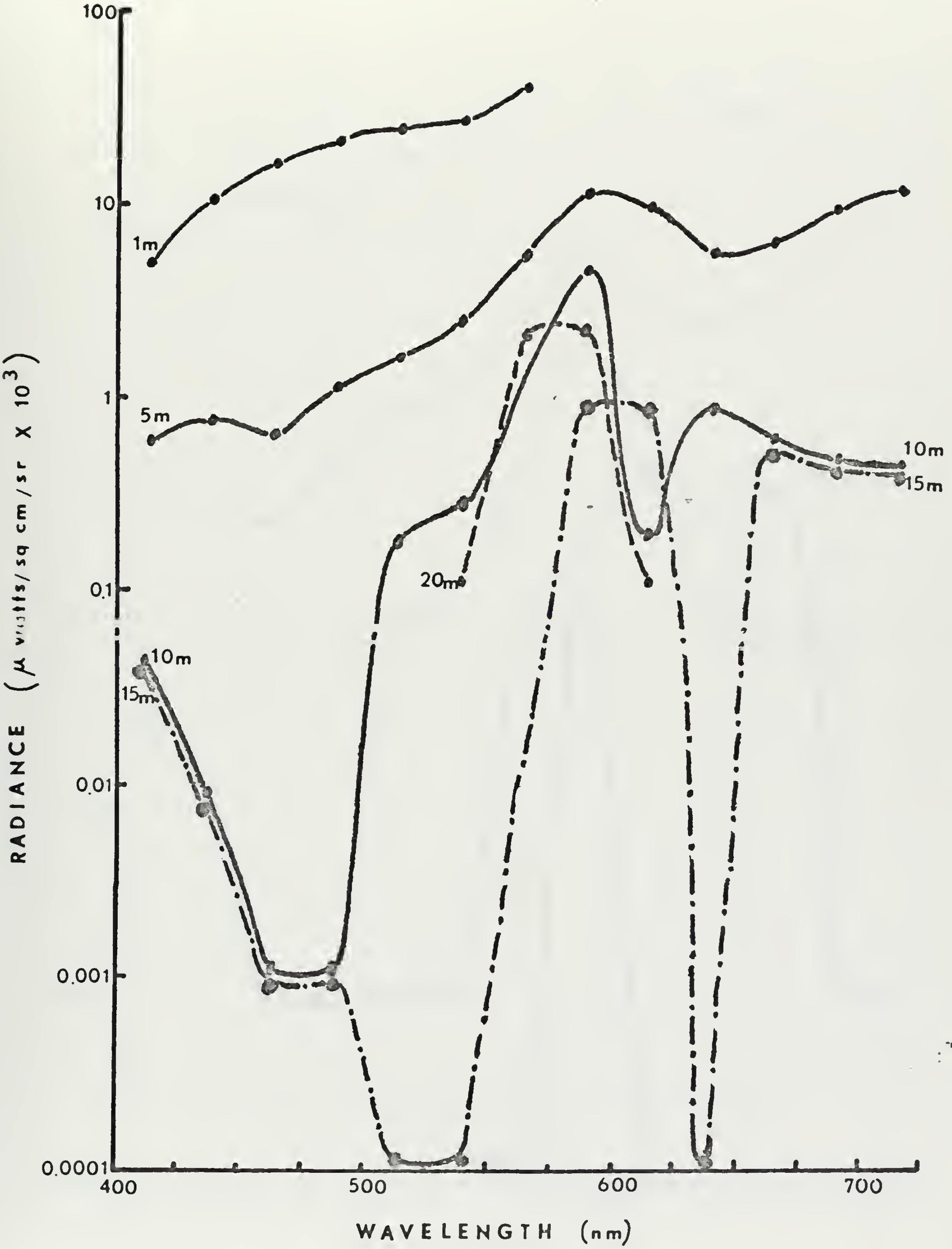


FIGURE 30. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 135°$ AND $\phi = 0°$, STA 2

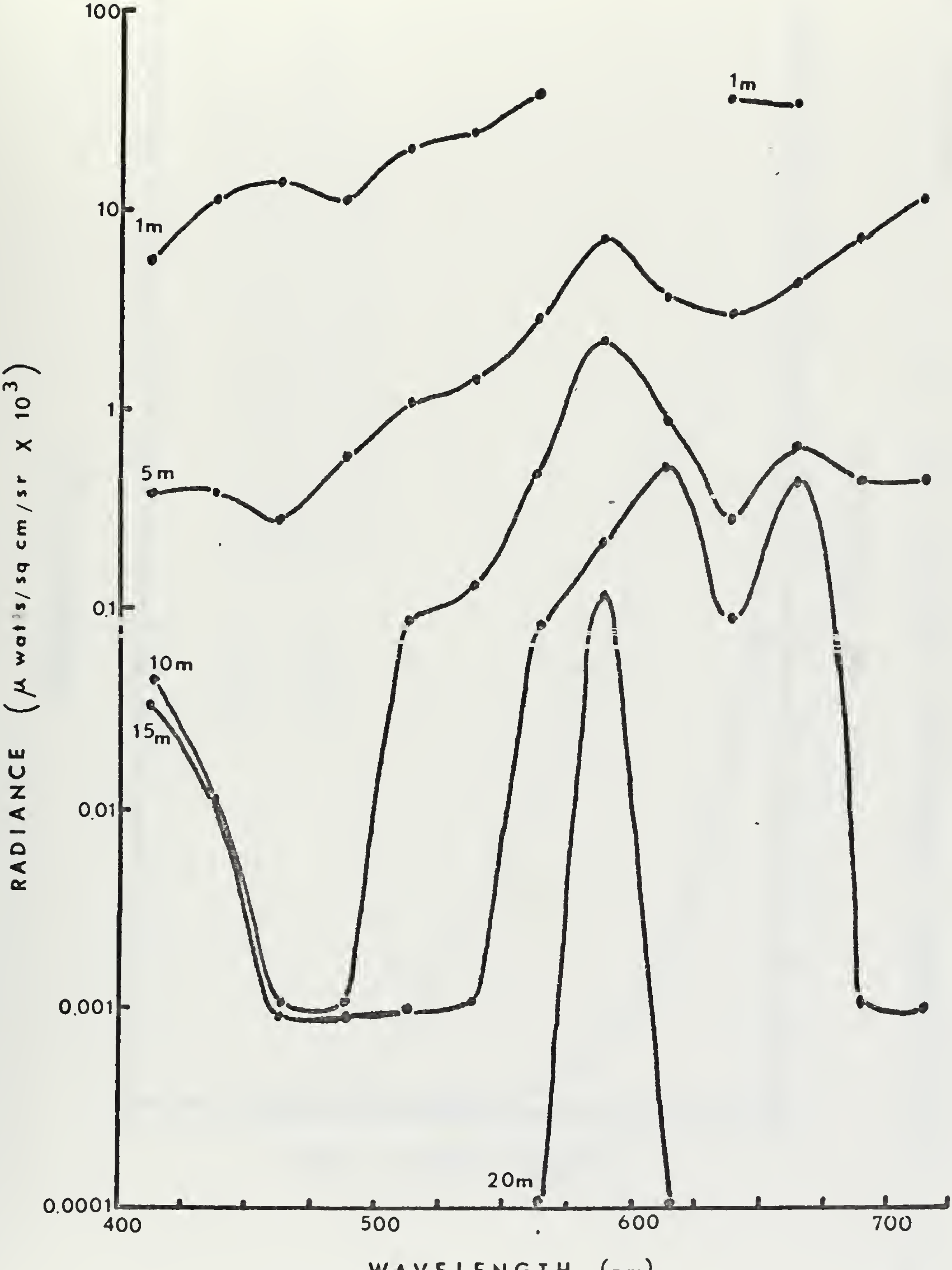


FIGURE 31. SPECTRAL RADIANCE DISTRIBUTION WITH DEPTH AT $\Theta = 166°$ AND $\phi = 0°$, STA 2

<u>APPENDIX B</u>

Spectral Radiance Calibration Nomograms for 25 nm Wavelength Bands from 400 to 725 nm.

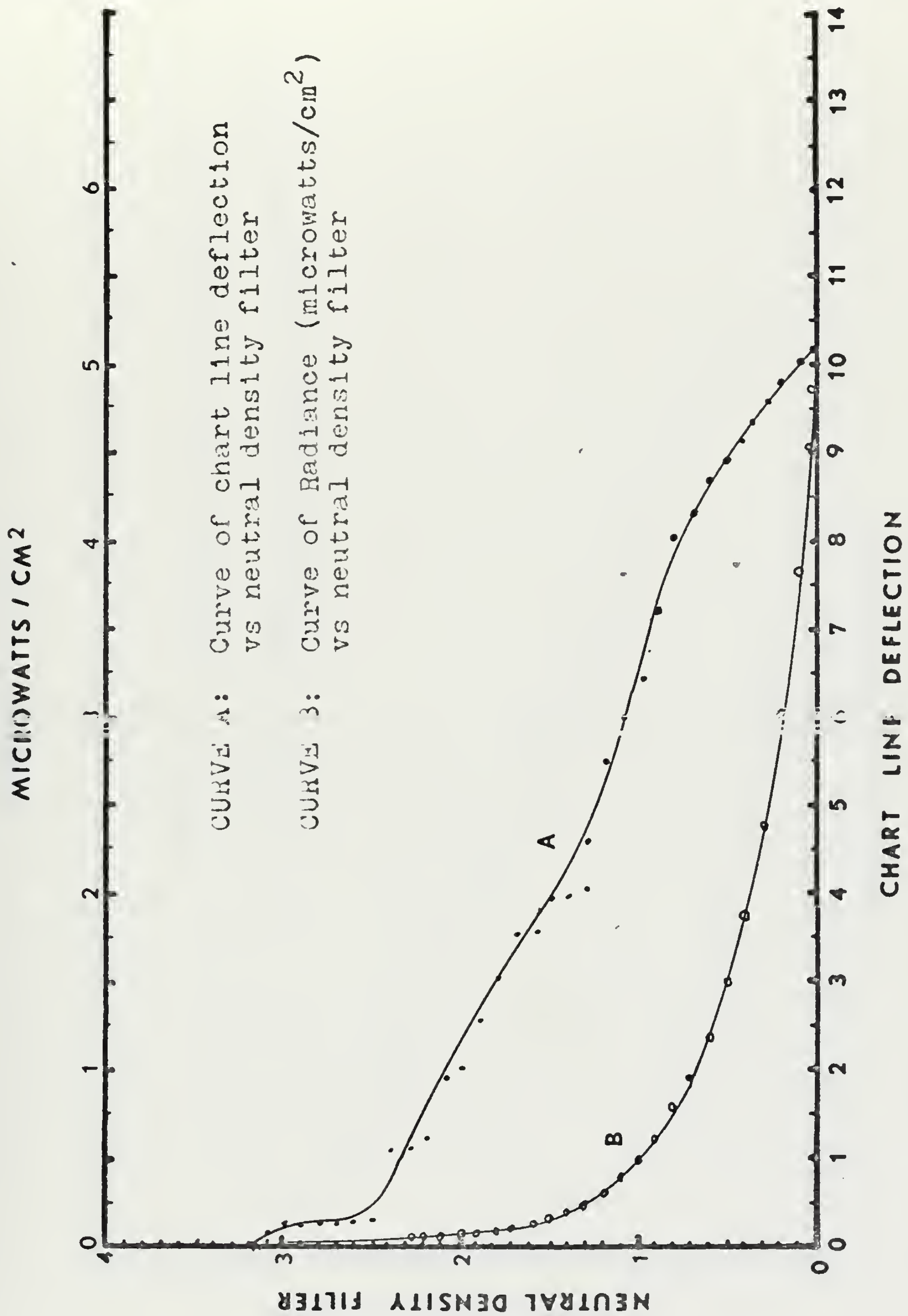


FIGURE 32. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 400-425 nm WAVELENGTH BAND

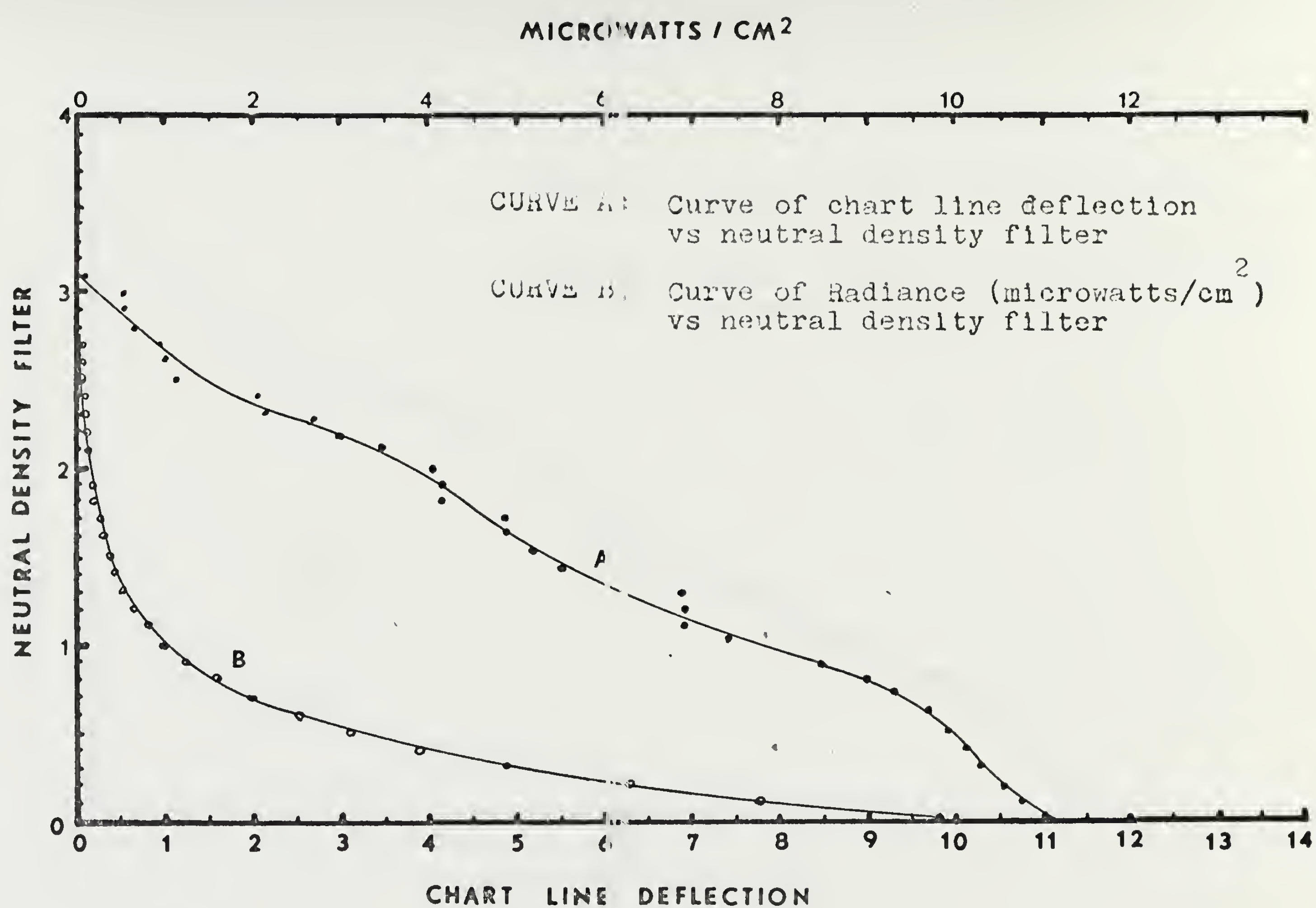


FIGURE 33. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 425-450 nm WAVELENGTH BAND.

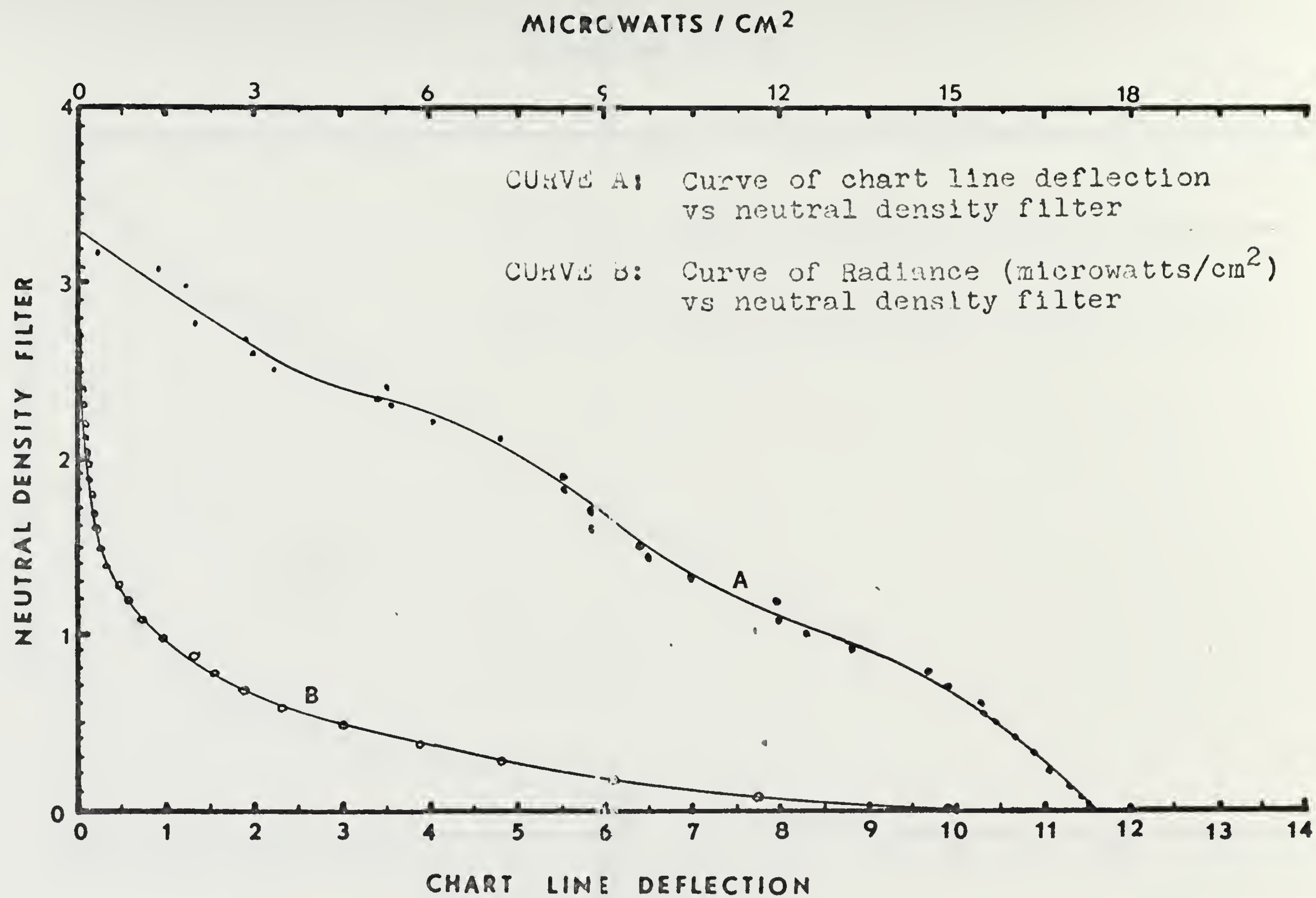


FIGURE 34. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 450-475 nm WAVELENGTH BAND.

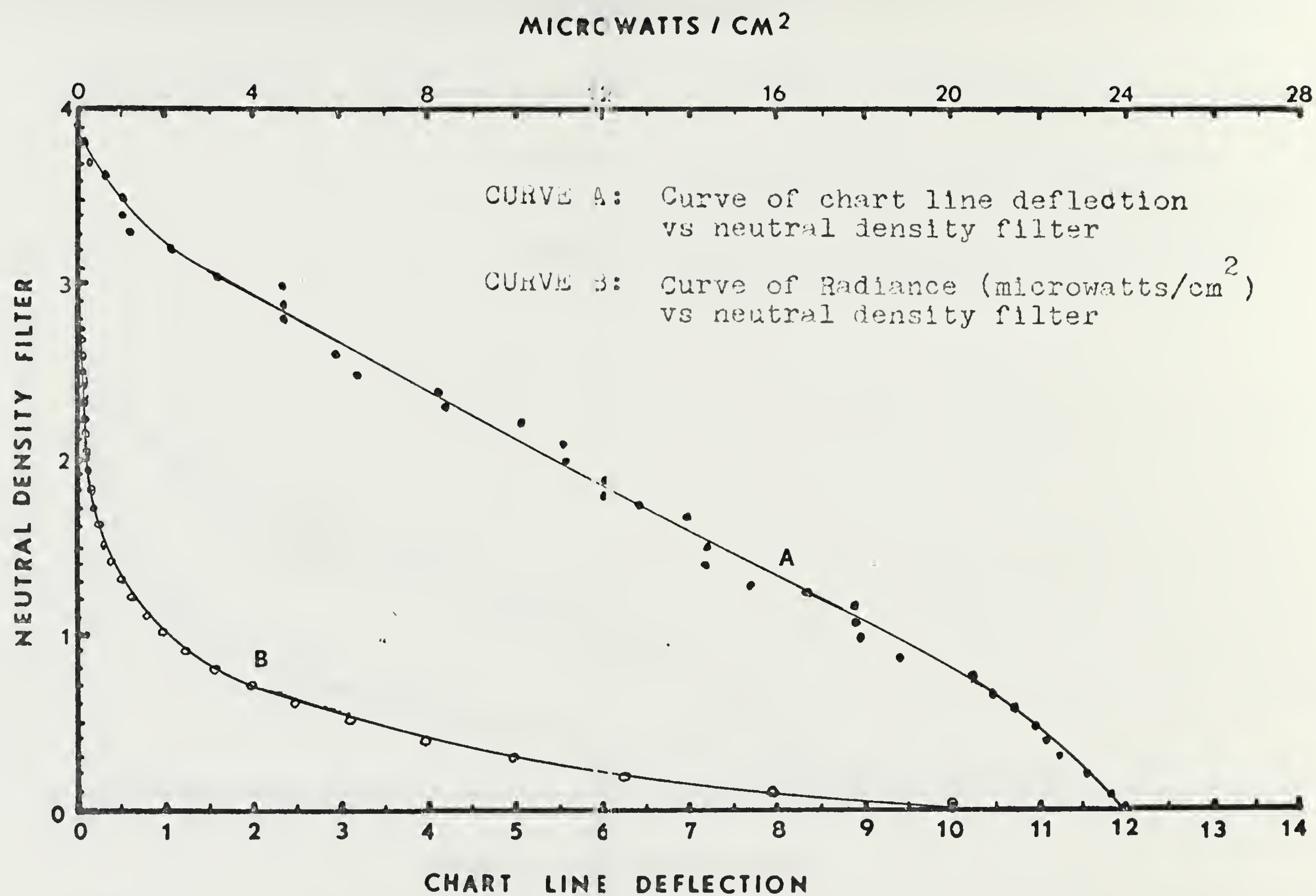


FIGURE 35. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 475-500 nm WAVELENGTH BAND.

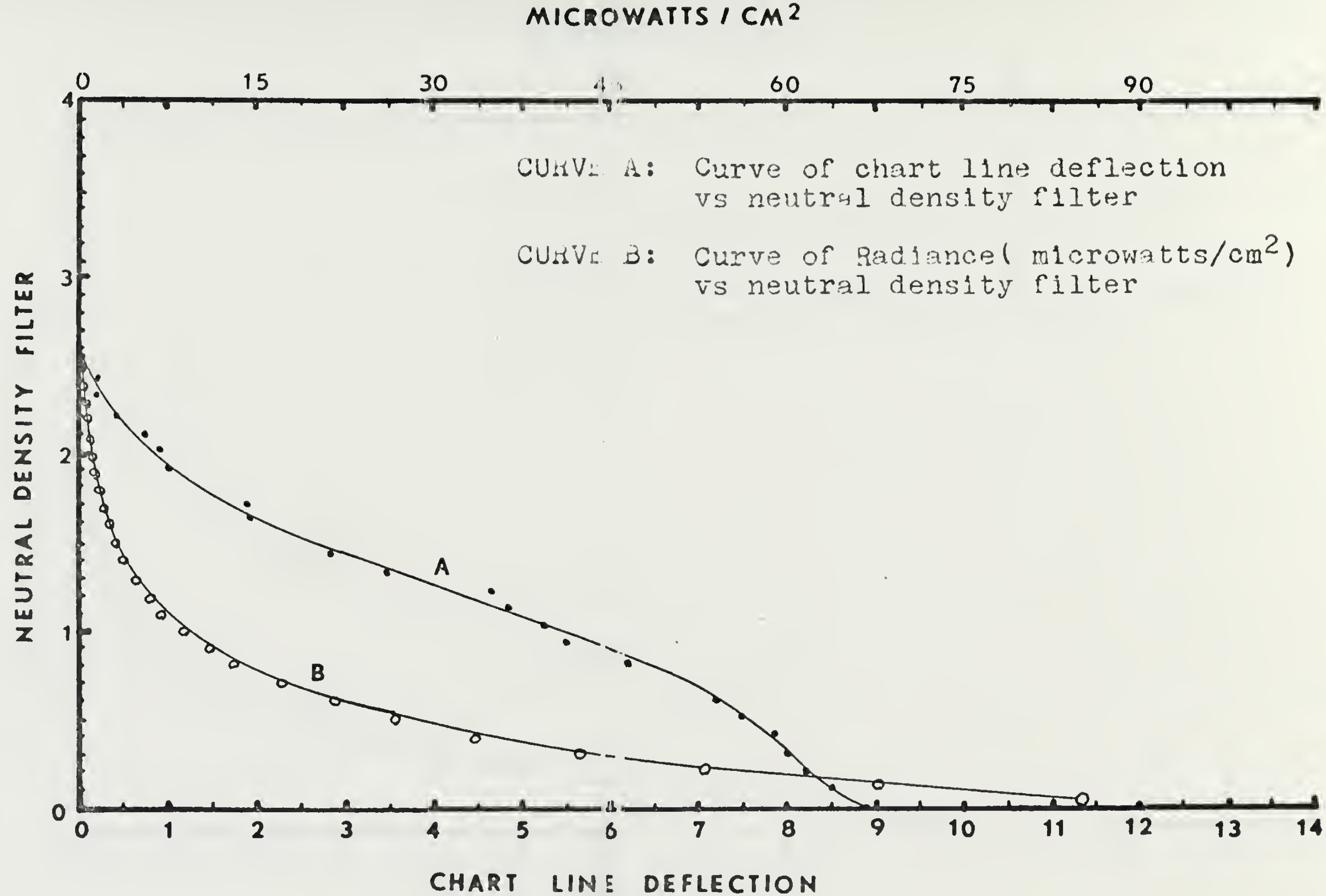


FIGURE 36. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 700-725 nm WAVELENGTH BAND.

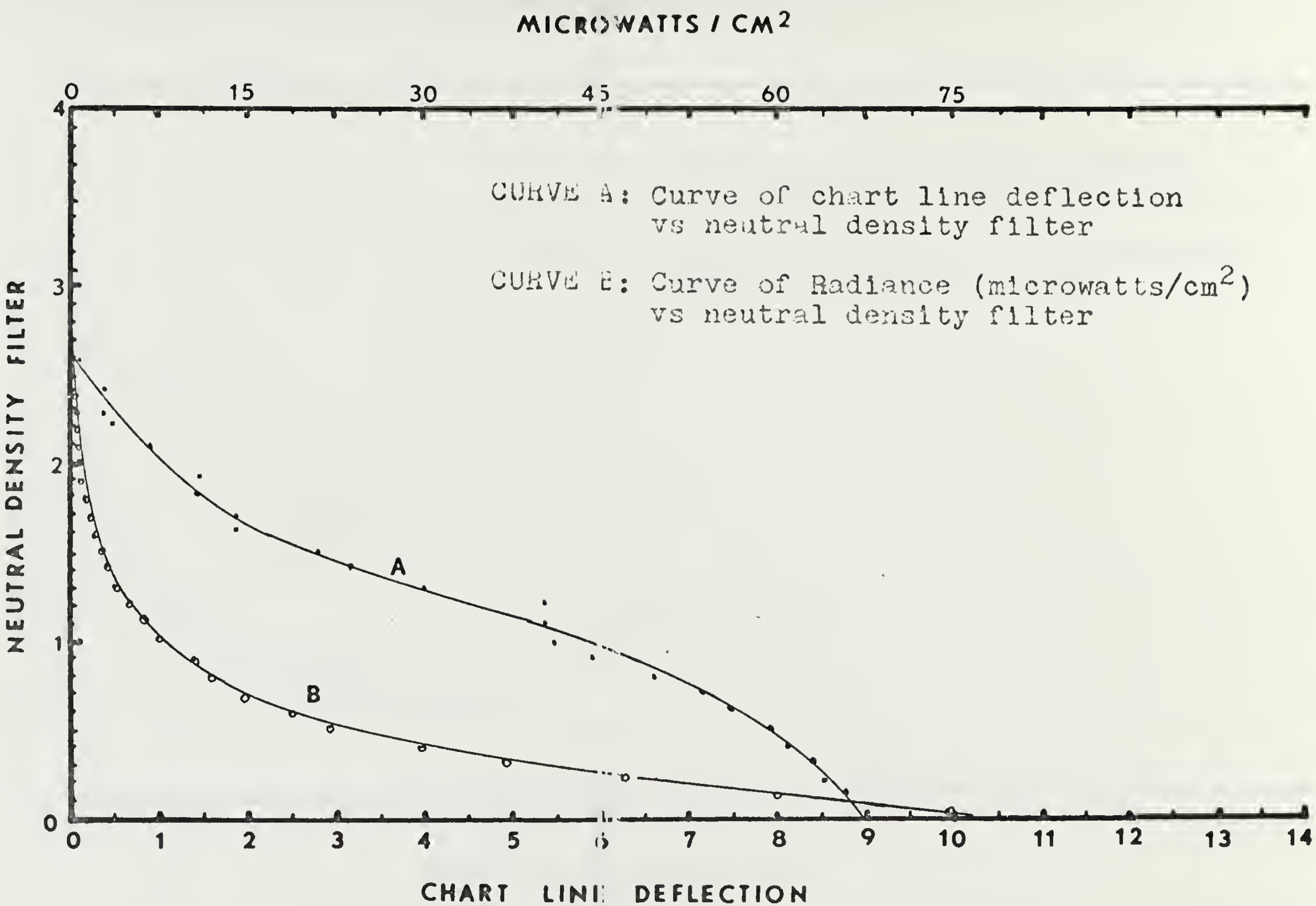


FIGURE 37. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 675-700 nm WAVELENGTH BAND.

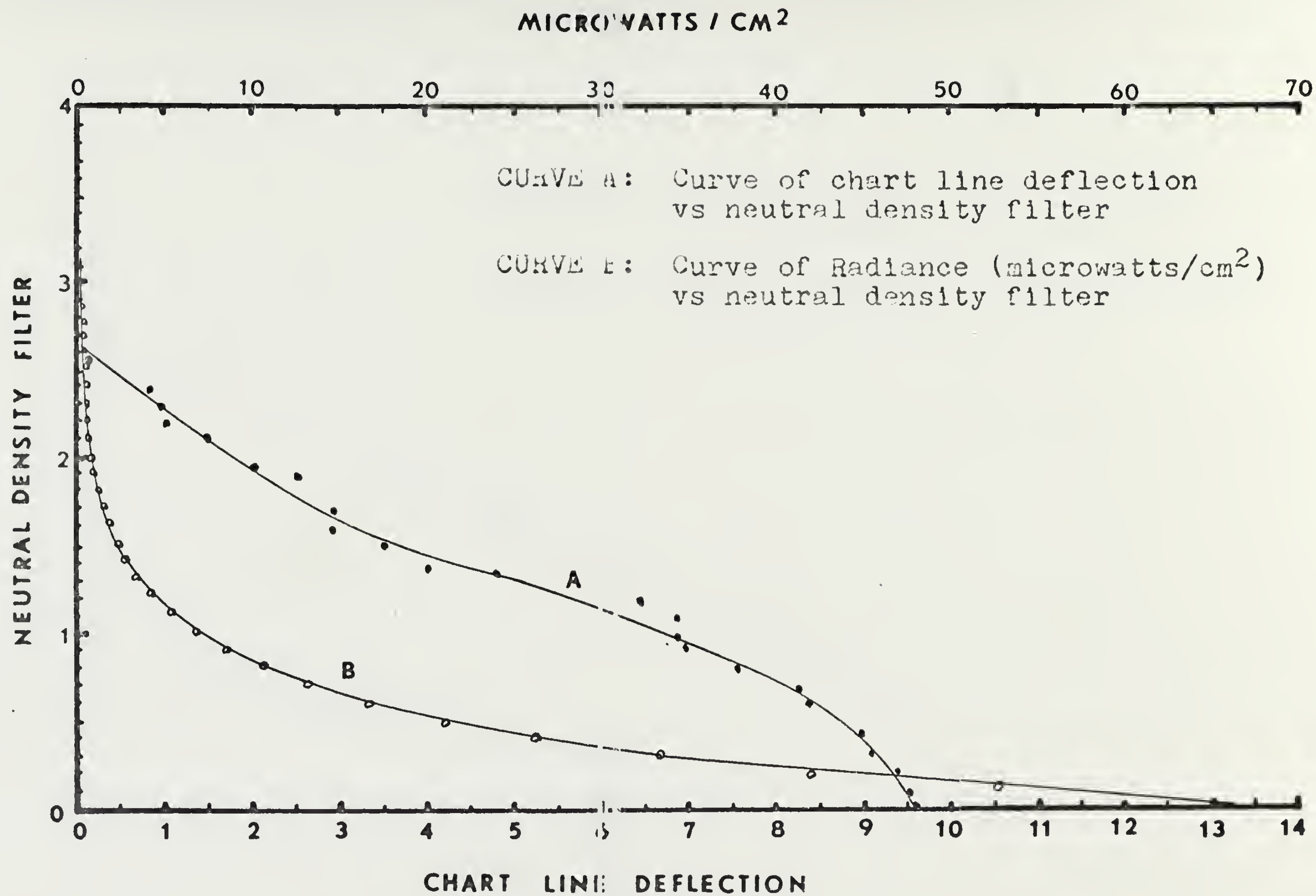
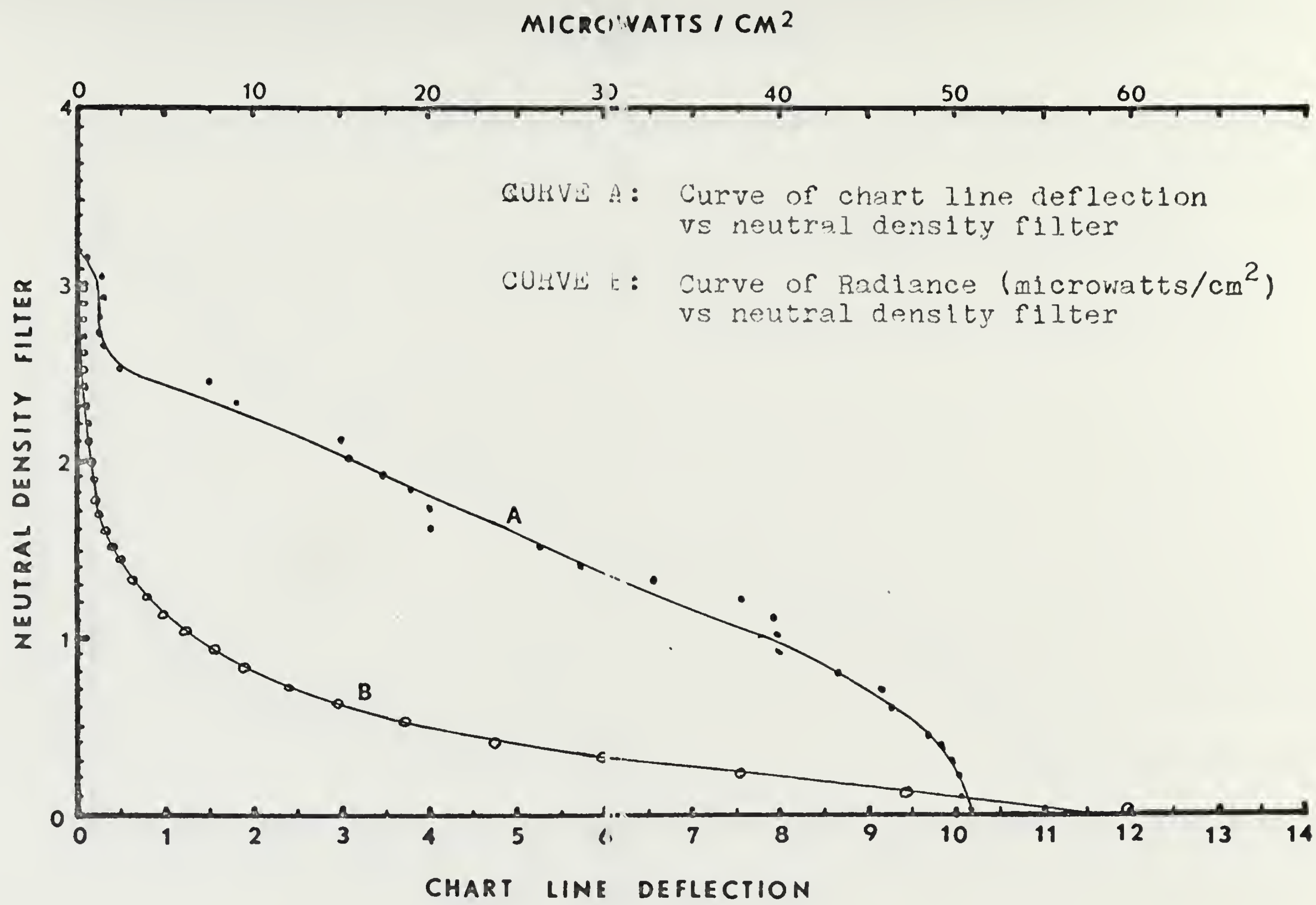


FIGURE 38. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 650-675 nm WAVELENGTH BAND.



. FIGURE 39. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 625-650 nm WAVELENGTH BAND .

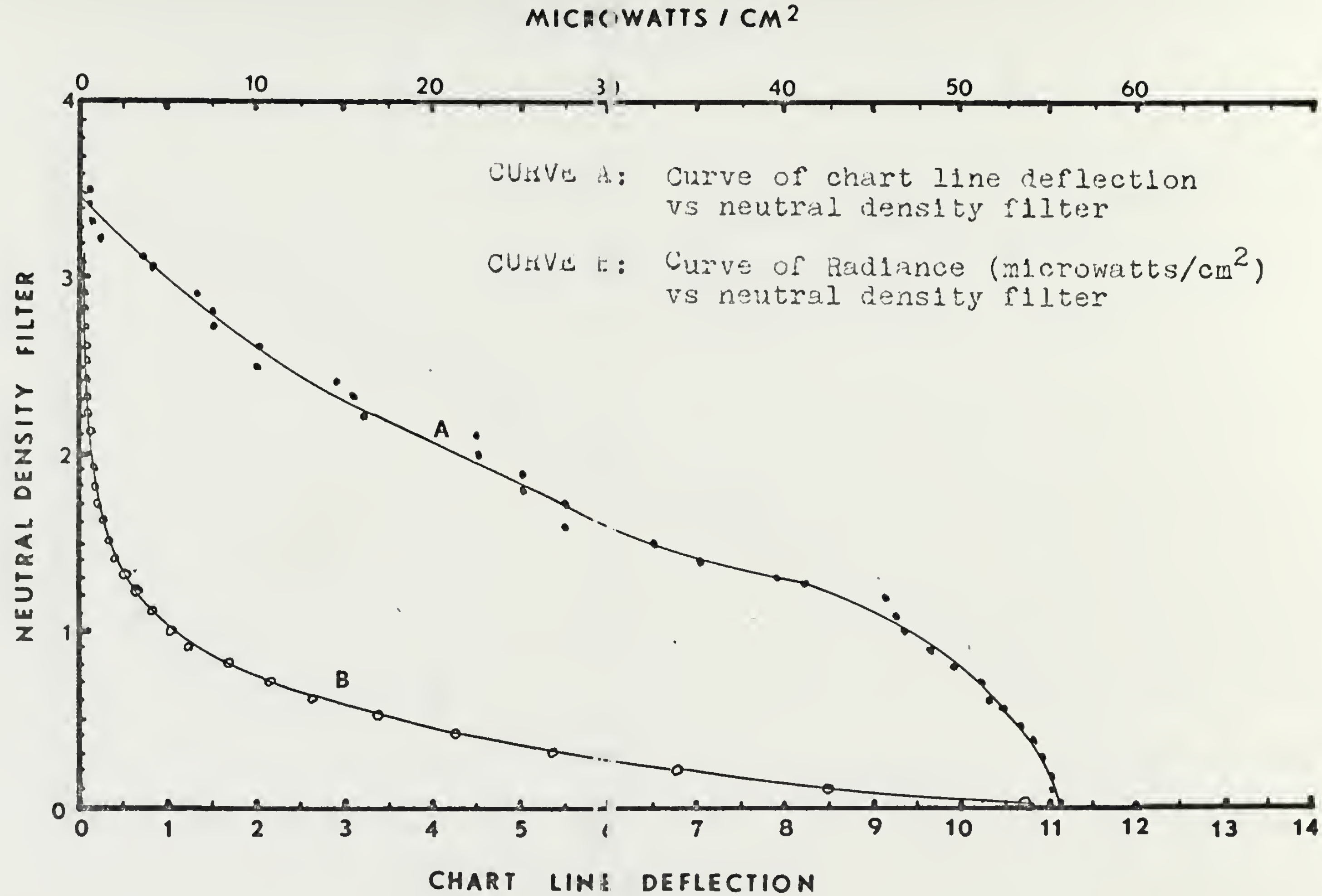


FIGURE 40. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 600-625 nm WAVELENGTH BAND.

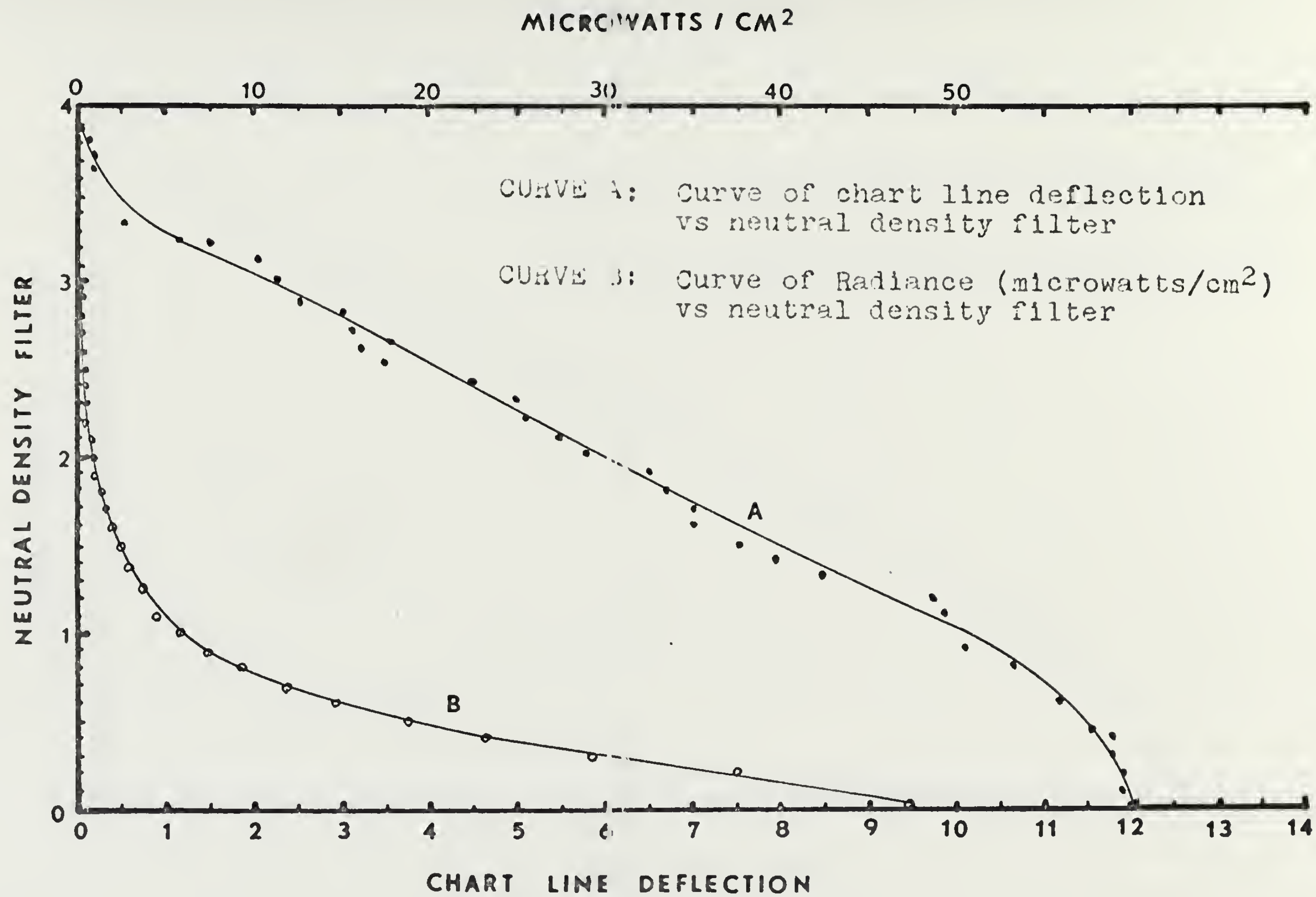


FIGURE 41. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 575 - 600 nm WAVELENGTH BAND .

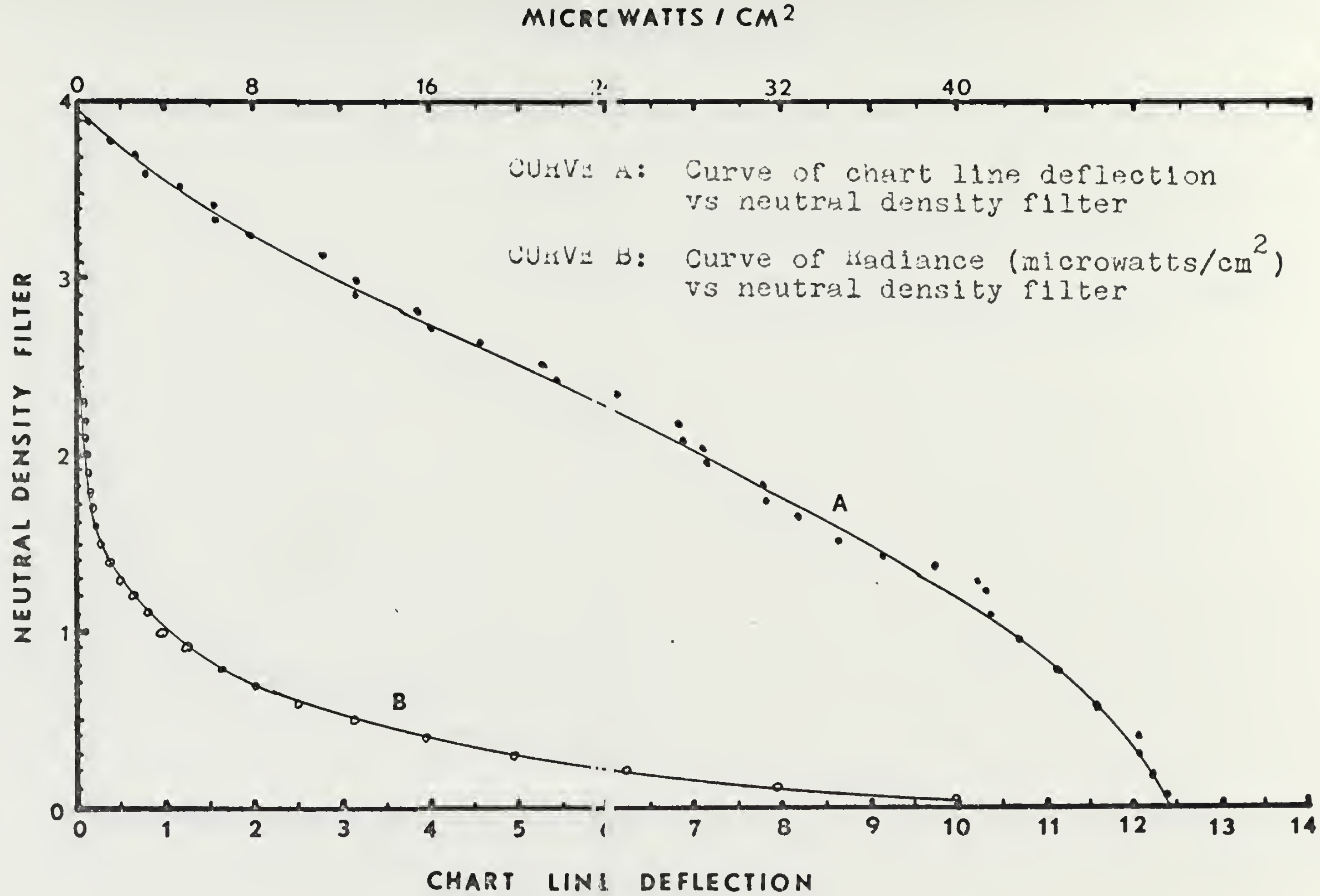


FIGURE 42. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 550-575 nm WAVELENGTH BAND.

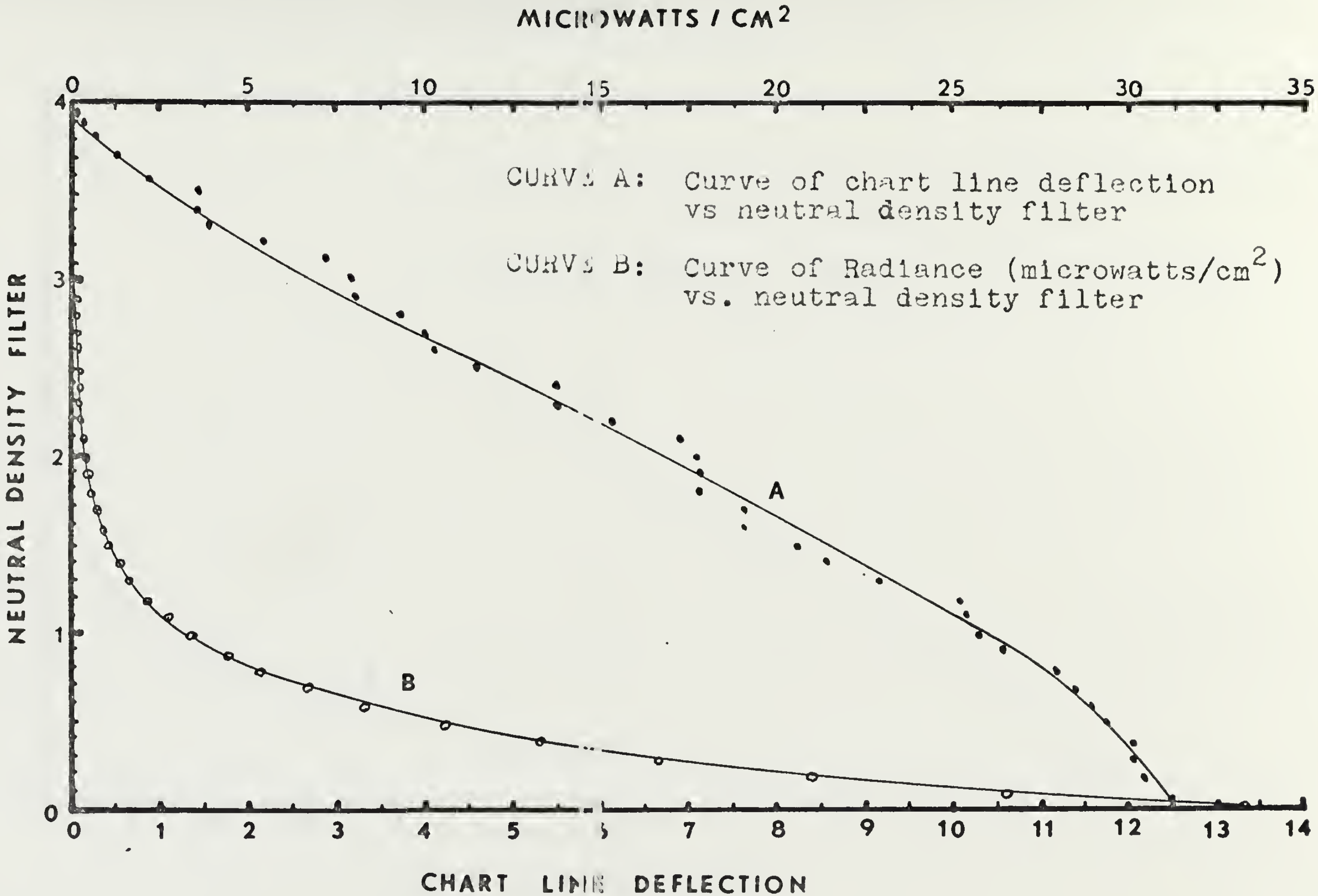


FIGURE 43. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 525-550 nm WAVELENGTH BAND.

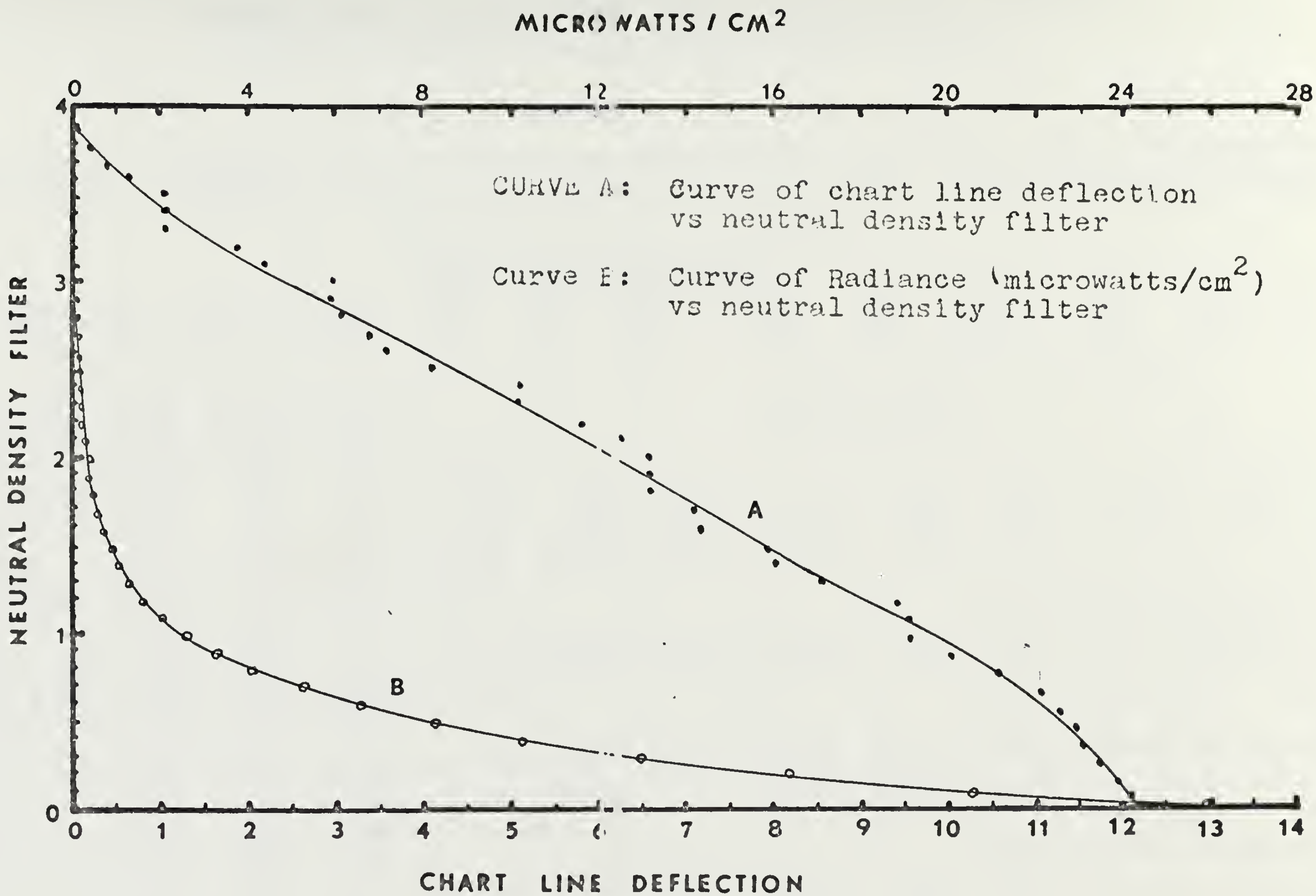


FIGURE 44. SPECTRAL RADIANCE CALIBRATION NOMOGRAM FOR 500 - 525 nm WAVELENGTH BAND.

APPENDIX C

Station Data: Location, Date, Time, Depth, Weather, Altitude of the Sun, Azimuth of the Sun, Radiance Measurements.

Station 1

Latitude: 36-38.8 N Longitude: 121-52.6 W Date: 16 July 1971 Local Time: 1255-1325 Sea: 230-1/2
Swell: 260-2 Sky: Partially Overcast Average Altitude of the Sun: 69° Average Azimuth of the Sun: 180°T

Radiance (μw/ cm^2 /sr X 10^3)

Wavelength Bands (nm)

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
0°	10m	264	9.22	9.39	15.09	20.45	*	*	*	9.89	8.22	24.73	52.81	*	*
		000	9.14	8.80	15.09	21.46	*	*	*	40.23	45.26	*	*	*	*
		270	*	8.21	8.80	16.76	21.79	*	*	*	*	*	*	*	*
	20m	130	5.45	0.59	.59	1.68	2.85	5.24	17.60	2.31	2.10	3.35	5.36	9.01	11.74
		000	*	0.75	.67	1.68	2.85	5.24	17.60	5.03	2.51	3.35	4.61	6.71	9.47
45°	10m	166	*	3.27	6.54	10.56	17.60	20.18	20.18	2.35	2.18	6.29	6.29	11.24	41.07
		184	3.47	3.35	6.71	16.60	19.28	*	*	*	*	*	*	*	*
		081	*	8.21	8.80	16.76	*	*	*	*	*	39.40	54.48	63.70	*
		122	.50	.84	1.09	1.68	3.52	14.17	15.09	5.45	2.93	5.45	6.71	12.57	19.28
		039	3.73	4.19	4.61	10.48	17.18	*	*	*	*	*	*	*	*
		000	*	8.30	11.32	17.02	*	*	*	*	*	47.78	39.40	*	*
		263	1.00	1.17	1.68	3.02	5.36	12.57	17.60	39.40	46.10	39.40	24.31	39.40	64.54
		292	*	5.87	6.71	10.48	17.18	27.65	*	39.40	15.93	12.57	8.38	18.48	37.72
		039	*	8.21	6.87	16.85	*	*	*	*	*	*	*	*	*
		081	*	8.21	8.80	16.76	*	*	*	*	*	39.40	54.48	63.70	*
		234	1.59	1.51	1.84	5.28	6.29	7.71	10.90	10.90	5.03	6.71	5.87	8.80	12.57
		181	3.47	3.35	6.71	16.60	19.28	*	*	*	*	*	*	*	*

θ	Depth	ϕ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
45°	20m	234	8.21	8.21	15.09	21.46	*	*	*	5.03	5.45	15.51	5.45	*	*
		105	*	.17	.17	.34	.92	1.42	2.51	.84	.42	.42	.63	1.34	2.10
		309	*	.51	.59	1.01	1.51	2.26	5.20	1.05	.25	.08	.42	.42	1.09
		194	.17	.34	.42	1.01	1.84	4.19	5.36	2.93	2.10	1.68	1.68	2.51	3.19
		341	2.93	5.03	.84	1.68	2.26	4.53	5.03	2.93	2.60	.84	3.35	3.77	4.61
		000	2.51	.42	.42	1.01	2.26	5.87	6.71	6.87	2.93	1.26	3.35	6.29	9.64

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
90°	3m	000	4.15	3.94	4.36	6.71	9.22	8.47	13.41	12.74	10.48	37.72	18.02	45.26	69.15
		071	4.21	4.08	4.29	6.62	9.01	7.10	10.25	11.31	10.21	32.12	15.00	41.02	61.11
		142	3.95	3.50	4.21	6.43	8.68	5.02	5.11	8.99	10.11	40.01	41.28	50.85	*
		322	1.09	1.09	1.26	1.68	2.01	2.10	1.26	3.35	2.51	4.19	6.71	13.41	22.63
	5m	000	5.30	5.28	9.90	10.73	17.60	27.24	13.41	20.54	8.38	37.72	19.70	46.10	*
		020	3.89	3.55	4.35	5.02	7.91	9.53	8.03	8.81	5.11	5.85	9.52	20.10	48.31
		098	5.01	4.77	5.53	2.54	9.22	9.22	13.41	5.03	4.61	7.54	10.06	19.70	49.45
	7m	000	.89	1.34	1.43	2.35	4.55	5.24	8.74	5.02	3.77	5.41	10.00	15.71	22.78
		079	.85	1.30	1.40	2.28	4.29	5.15	8.65	5.05	3.60	5.29	9.90	14.85	21.65
	10m	033		.25	.17	1.01	1.34	1.59	2.51	1.26	1.04	1.05	3.35	5.20	6.71
		176		.25	.17	.84	1.34	1.68	2.51	2.10	1.26	1.04	2.72	5.11	6.71
		163	.08	.25	.008	.42	.84	1.68	1.17	2.10	1.68	.84	.84	1.68	2.51
		078	.21	.34	.42	.84	2.51	4.19	4.19	3.77	2.10	2.10	3.35	5.87	7.12
		000	.46	.92	1.26	2.18	2.51	5.03	6.54	11.74	14.67	4.61	3.35	6.29	10.06
		297	.38	.84	.50	1.21	2.51	4.61	5.36	7.12	2.93	4.61	3.35	6.29	10.06
		329	.50	.75	.75	.84	2.51	10.48	5.36	7.12	2.51	4.61	2.51	5.45	6.71
		111	1.01	1.17	1.27	1.68	1.68	3.19	9.05	10.48	2.10	2.93	3.35	6.29	10.06
		260	.25	.42	.34	.42	.84	1.59	2.68	5.45	2.51	1.26	2.51	3.77	5.03
	20m	000	0	.001	.01	.17	.17	.25	.42	.001	.001	.001	.001	.001	0
		167	0	.08	.08	.17	.34	.34	.34	.42	.001	.001	.001	.0001	0
		294	.042	.042	.008	.25	.586	.84	1.68	1.68	.84	.42	.17	.42	.008
		067	.50	.042	.017	.251	.42	.84	.84	1.93	.84	.42	.34	.42	.008
		137	.001	.001	.008	.167	.167	.420	.670	.84	.67	.34	.47	.42	.34
		104	.001	.001	.008	.13	.17	.34	.42	1.26	.50	.50	.42	.59	.34
		000	.008	.050	.017	.34	.84	1.26	1.26	.84	2.10	.84	.50	.67	.50

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
135°	3m	000	.92	2.15	2.52	9.21	5.01	6.00	[illegible].28	8.61	6.14	6.34	10.14	13.38	30.15
		334	.85	1.34	1.68	2.35	3.19	3.02	[illegible].26	3.35	3.35	6.29	9.22	11.24	22.63
	5m	251	.922	.922	.922	.922	2.01	2.01	[illegible].60	3.35	2.93	5.45	9.72	16.55	26.82
		000	.922	.922	.922	.922	2.01	2.18	1.60	3.35	2.93	5.45	9.72	16.55	26.82
	7m	000	1.27	1.29	1.15	2.31	3.51	3.65	1.81	5.28	4.25	4.03	3.54	1.10	1.19
		143	.82	.84	.75	.84		1.05	1.47	2.18	2.51	5.45	9.22	15.51	22.63
	10m	122	.04	.08	.08	.34	.84	.42	.59	.08	.001	.001	.001	.84	.84
		340	.04	.08	.08	.16	.42	.38	.59	.08	.001	.001	.001	.84	.84
		098	.04	.08	.08	.17	.34	.50	.67	1.67	1.51	1.09	.84	.84	.84
		303	.04	.08	.17	.25	.34	.50	1.01	2.10	1.26	.34	.84	1.67	2.51
		340	.05	.08	.08	.25	.34	.50	.84	1.68	1.26	.34	.34	.84	.84
		000	.08	.08	.17	.25	.42	2.10	2.10	2.51	1.68	1.26	.34	2.10	1.68
		137	.59	.08	.08	.25	.34	.50	1.01	2.51	2.10	1.26	.92	2.10	2.51
	20m	341	.0006	.001	.001	.001	.001	.21	.08	.001	.001	.001	.001	.001	0
		118	.0007	.001	.001	.001	.08	.21	.08	.001	.001	.001	.001	.001	0
		176	.0008	.008	.008	.008	.012	.251	.08	.17	.008	.17	.08	.59	.008
		120	.0008	.008	.008	.008	.042	.251	.083	.008	.008	.34	.17	.59	.008
		000	.042	.008	.0008	.008	.017	.251	.084	.034	.503	.251	.084	.419	.008
166°	3m	000	1.71	1.73	2.19	2.87	3.68	4.19	4.93	5.21	3.89	4.51	4.72	17.29	25.18
		120	1.60	1.51	1.93	2.85	3.02	3.86	2.51	3.77	2.93	5.45	19.11	16.76	22.63
		209	.93	.92	.75	1.34	1.34	1.51	.75	2.18	2.10	4.19	6.37	10.48	14.25
	5m	000	.99	1.01	1.26	2.01	1.84	2.31	4.02	3.35	2.51	5.45	12.57	16.76	25.15
		314	.90	.92	.92	2.01	1.84	3.86	2.43	3.77	2.93	5.45	12.57	16.76	25.15
	7m	000	.65	.75	.59	.67	1.17	1.26	1.68	2.93	2.51	5.45	4.80	3.83	1.97
		136	.59	.75	.59	.82	1.01	1.26	1.68	2.10	2.51	5.45	4.80	3.83	1.97
	10m	232	.04	.08	.08	.08	.17	.21	.82	.34	.34	.001	.82	1.01	1.68
		244	.04	.08	.08	.08	.17	.21	.82	.82	.34	.001	.41	.82	2.10
		201	.042	.06	.008	.17	.42	.50	.50	1.26	.84	.42	.42	1.01	1.68
		021	.05	.08	.008	.17	.37	.67	.84	1.68	.92	.59	.50	.92	1.68

*Values exceed limitations of standard lamp

Station 2

Latitude: 36-39.7 N Longitude: 121-53.7 W Date: 16 July 1971 Local Sun Time 1410-1440
Sea: 230-1/2. Swell: 230-2. Sky: Overcast. Average Altitude of the Sun: 65°. Average Azimuth of the Sun: 230°T

Radiance ($\mu w/ cm^2 /sr \times 10^3$)

Wavelength Bands (nm)

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
0°	5m	000	5.12	10.98	16.51	23.30	23.64	*	*	*	*	*	*	*	*
		298	5.00	10.88	16.43	23.10	22.64	*	*	*	*	*	*	*	*
	10m	000	.67	.84	1.17	2.93	9.22	14.00	*	*	*	39.40	19.70	44.30	69.20
		050	1.09	.92	1.34	4.27	7.04	9.64	33.53	*	*	10.51	7.52	11.74	15.30
	15m	235	.34	.17	.17	.50	1.34	2.18	10.06	24.31	8.38	2.10	2.10	3.35	5.03
		000	.17	.17	.17	.34	1.34	1.51	10.06	39.40	8.38	5.03	4.19	4.19	5.45
		074	.21	.42	.25	1.68	2.35	7.71	10.56	4.19	2.68	3.35	3.35	5.03	6.29
		185	.08	.25	.17	1.01	1.76	4.61	15.09	4.19	2.68	5.45	5.45	6.29	9.64
	20m	000	.08	.04	.04	.17	.34	.67	2.10	8.21	2.35	1.26	2.10	1.68	2.51
	25m	000	.075	.059	.034	.168	.335	.838	1.005	2.515	.838	.251	.419	.671	.671
		024	.034	.008	.025	.042	.754	2.096	1.676	1.676	.503	.251	.335	.419	.419
		161	.050	.008	.084	.335	1.090	2.514	1.676	2.096	.838	.419	.419	.503	.587
		240	.04	.01	.001	.083	.17	.29	.50	1.09	0.84	0.42	0.42	0	0
	30m	188	.008	.008	.034	.042	.17	.29	.84	1.86	1.26	.42	.42	0	0
		032	.008	.008	.034	.042	.17	.34	.84	1.26	.34	.42	.167	0	0
		292	.0008	.001	.0008	.042	.084	.251	1.676	.419	.335	.017	.419	.167	.419
		188	.008	.008	.034	.042	.17	.29	.84	1.86	1.26	.42	.42	0	0
		032	.008	.008	.034	.042	.17	.34	.84	1.26	.34	.42	1.67	0	0
		136	.0008	.001	.008	.084	.042	.419	.838	.671	.251	.017	.419	0	0
		000	.017	.017	.0008	.084	.167	1.257	1.005	1.676	.838	.335	.419	.167	.419
		070	.025	.034	.008	.042	.008	1.676	1.005	.419	.335	.335	.419	.167	.335

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
	40m	287	0	0	0	0	.083	.251	.025	.628	.42	.251	.083	0	0
		127	0	0	0	0	.083	.251	.025	.628	.42	.083	.083	0	0
		149	.0008	.001	.042	.168	.168	.838	.251	.838	.251	.083	.419	.0008	.084
		000	.034	.042	.017	.083	.168	.502	.587	.838	.168	.050	.419	.008	.084
		077	.034	.838	.0008	.042	.083	.419	.503	.671	.251	.050	.419	.0008	.084
		194	.042	.017	.838	.042	.042	.419	.419	2.096	.838	.083	.419	.084	.084
	50m	241	0	0	0	0	0	.083	.167	.167	0	0	0	0	0
		209	0	0	0	0	0	.083	.095	.167	0	0	0	0	0
		111	0	0	0	0	0	.083	.083	.251	0	0	0	0	0
		032	.042	.017	.0008	.017	.008	.419	.168	.671	.838	.042	.008	.008	.083
		000	.042	.001	.0008	.042	.042	.419	.168	.838	.251	.419	.419	.083	.419
		205	.034	.017	.0008	.083	.419	.419	.168	.754	.335	.419	.419	.083	.503
	60m	041	0	0	0	0	0	.083	0	0	0	0	0	0	0
		260	0	0	0	0	0	.083	0	0	0	0	0	0	0
		231	.0008	0	0	.008	.017	.168	.042	.042	.008	0	0	0	0
		000	.017	0	0	.042	.084	.168	.042	.042	.008	.084	0	0	0
		150	.008	0	0	.008	.0008	.168	.034	.042	.004	.167	0	0	0
45°	1m	334	6.62	13.33	19.36	25.31	*	*	*	*	*	*	*	*	*
		039	5.53	11.06	16.76	22.63	*	*	*	*	*	*	*	*	*
		000	6.28	12.41	18.78	24.81	*	*	*	*	*	*	*	*	*
		263	5.78	16.42	18.69	24.81	*	*	*	*	*	*	*	*	*
		217	6.20	16.66	18.69	24.48	*	*	*	*	*	*	*	*	*
	5m	000	6.45	17.95	18.74	24.81	*	*	*	*	*	*	*	*	*
		303	5.45	10.81	16.35	22.46	*	*	*	*	*	*	*	*	*
		176	5.78	11.65	17.60	24.31	*	*	*	*	*	*	*	*	*
		149	5.88	11.82	17.17	24.31	*	*	*	*	*	*	*	*	*
		025	4.86	9.64	15.09	20.96	20.12	*	*	*	*	*	*	*	*

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
45°	10m	026	.34	.25	.17	.84	1.34	2.18	8.55	37.22	38.56	8.38	6.71	11.32	18.86
		000	1.51	1.17	1.51	3.77	8.55	12.74	*	*	*	*	15.51	23.47	44.41
		045	.34	.34	.25	1.01	1.93	5.28	17.60	*	*	15.51	7.96	11.32	20.96
		072	.75	1.01	1.26	3.02	6.20	8.23	*	*	*	15.51	10.06	12.57	20.96
	15m	201	.083	.042	.017	.335	.42	1.09	3.44	19.28	3.77	5.45	3.77	5.28	5.87
		227	.083	.083	.17	.59	1.51	2.18	5.62	3.21	8.38	4.19	3.77	5.03	5.87
		331	.13	.13	.17	.59	.92	2.18	8.47	32.10	5.45	4.19	3.77	5.45	5.87
		000	.34	.17	.17	.59	1.26	2.18	8.47	39.61	7.12	4.19	3.77	5.45	5.45
		301	.168	.251	.083	.671	3.856	7.711	17.602	18.860	2.682	2.515	3.352	5.029	6.287
		159	.117	.335	.251	1.005	2.347	7.711	10.897	6.873	2.682	2.933	2.096	2.515	2.934
	20m	340	.008	.01	.001	.01	.17	.34	.82	2.31	.82	.41	0	0	0
		000	.008	.042	.008	.17	.34	.63	2.10	6.54	2.51	.82	.63	1.68	.82
		085	.025	.042	.008	.168	.168	1.675	2.515	2.933	.838	.419	.419	.670	1.02
	25m	290	.042	.008	.001	.001	.001	.003	.251	.63	2.93	.92	.42	0	0
		111	.034	0	0	0	0	.03	.167	.251	.042	.01	0	0	0
		101	.034	0	0	0	0	.03	.08	.63	.042	.08	0	0	0
		044	.059	.059	.013	.008	.335	.838	.251	.419	.419	.083	.419	.503	.419
		000	.042	.008	.008	.167	.419	1.257	.922	3.608	.831	.419	.503	.670	.838
		334	.042	.008	.0008	.008	.084	.419	.671	1.257	.503	.335	.419	.670	.838
		018	.050	.017	.008	.084	.168	.838	.671	1.257	.587	.335	.419	.502	.502
		162	.075	.042	.042	.168	.335	1.844	1.676	.838	.587	.335	.410	.419	.419
	30m	136	0	0	0	0	.08	.167	.251	.51	.042	0	0	0	0
		036	0	0	0	0	.08	.167	.21	.13	.042	0	0	0	0
		341	0	0	0	0	0	.042	0	.168	.042	0	0	0	0
		181	.422	.0008	.0008	.001	.008	.251	.167	.419	.167	.167	0	0	0
		018	.050	.042	.001	.001	.008	.167	.167	.419	.419	.008	0	0	0
		000	.008	0	0	.001	.008	.251	.251	.587	.084	0	0	0	0
	40m	276	0	0	0	0	0	.08	.001	.13	.008	0	0	0	0
		240	0	0	0	0	.042	.03	.001	.07	.008	0	0	0	0
		122	0	0	0	0	.042	.034	.001	.13	.008	0	0	0	0
		201	.042	.025	.0008	.001	.025	.158	.126	.168	.001	0	0	0	0

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
	40m	070	.025	.017	.0008	.001	.008	.168	.126	.168	.083	.335	.250	.314	.319
		000	.025	.025	.0017	.001	.017	.168	.335	.838	.671	.335	.335	.400	.510
		156	.042	.025	.0017	.0008	.008	.251	.335	.838	.671	.335	.335	.419	.675
	50m	086	0	0	0	0	0	0	0	.008	0	0	0	0	0
		000	0	0	0	0	0	0	0	.008	0	0	0	0	0
	60m	151	0	0	0	0	0	0	0	.008	0	0	0	0	0
		037	0	0	0	0	0	0	0	.008	0	0	0	0	0
		000	0	0	0	0	0	0	0	.017	0	0	0	0	0
90°	1m	000	5.53	10.98	16.35	21.79	*	*	*	*	*	*	*	*	*
		066	4.69	8.38	9.64	10.39	17.18	17.10	33.53	*	*	*	*	*	*
		354	5.03	10.06	15.26	20.45	*	*	*	*	*	*	*	*	*
		283	5.11	10.23	15.68	21.79	*	*	*	*	*	*	*	*	*
		211	5.03	10.06	15.08	20.28	20.96	20.37	33.53	*	*	*	*	*	*
	5m	160	5.03	9.89	14.92	20.28	*	*	*	*	*	*	*	*	*
		053	4.61	7.96	8.21	20.12	*	*	*	*	*	*	*	*	*
		000	5.36	10.81	16.35	21.96	*	*	*	*	*	*	*	*	*
		270	2.01	1.51	2.35	3.52	7.04	10.06	*	*	*	*	27.42	*	*
		213	.59	.75	1.09	1.51	1.34	2.51	5.62	11.74	14.75	6.29	7.54	12.99	36.0
	10m	000	.34	.59	1.09	2.35	4.86	7.46	20.11	*	*	38.98	9.22	12.15	18.44
		276	.08	.08	.08	.34	1.01	1.55	3.35	11.74	3.56	3.35	2.93	3.77	5.45
		221	.34	.34	.42	1.01	1.51	3.35	7.96	39.8	24.3	5.03	3.77	5.87	7.12
		265	.08	.01	.08	.167	.58	.63	.83	6.29	3.56	1.68	1.93	2.93	6.71
		335	.17	.17	.17	.42	1.01	2.51	6.29	18.86	8.80	4.19	3.77	3.77	5.87
		040	.08	.03	.08	.03	.59	1.16	5.45	18.86	8.89	4.19	4.19	5.87	7.12

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-65-	650-675	675-700	700-725
	15m	261	.04	.001	.001	.08	.17	.59	.08	4.61	1.68	.80	.42	.34	0
		306	.03	.01	.01	.01	.08	.21	.75	4.61	2.18	.80	.24	.80	.42
		000	.08	.042	.08	.17	.42	1.09	3.44	11.74	3.56	2.93	2.10	2.51	2.35
		075	.08	.08	.001	.17	.25	.42	1.68	9.22	2.68	2.93	1.26	2.10	2.35
		125	.08	.04	.008	.251	.59	1.09	3.27	10.48	2.68	2.77	1.26	1.68	1.68
		094	.042	.042	.008	.168	.335	3.352	3.688	3.269	1.676	1.257	1.676	2.514	2.933
		043	.050	.084	.034	.335	.503	4.191	4.359	1.844	.838	.670	.838	.838	2.096
		315	.084	.034	.001	.042	.168	.839	1.676	4.191	1.006	.67	.838	.754	1.006
	20m	256	.03	.04	0	0	.08	.21	.42	2.51	.82	.42	.42	0	0
		000	.08	.08	0	0	0	.08	.08	12.99	.42	0	0	0	0
		040	.042	.001	.001	.08	.251	.63	1.66	4.61	.75	0	0	0	0
	25m	089	.08	.001	.001	.008	.168	.042	.419	.419	.20	0	0	0	0
		039	.08	*	*	*	*	*	*	*	*	*	*	*	*
		321	.08	*	*	*	*	*	*	.17	*	*	*	*	*
		179	.067	.017	.001	.001	.008	.168	.042	.419	.419	.251	.167	.251	.838
		154	.050	.034	.001	.001	.008	.008	.084	.335	.251	.168	.168	.671	.922
		000	.042	.034	.001	.001	.008	.084	.084	.670	.419	.251	.419	.503	.587
	30m	351	0	0	0	0	0	0	0	.17	0	0	0	0	0
		299	0	0	0	0	0	0	0	.04	0	0	0	0	0
		000	.042	.034	.0003	.0008	.0008	.168	.084	.251	.084	.008	0	0	0
		031	.042	.034	.0002	.0001	0	.084	.042	.251	.008	.008	0	0	0
		235	.042	.034	.0002	.0001	.008	.042	.0008	.251	.008	0	0	0	0
		306	0	0	0	0	.0008	.168	.042	.168	.0008	.008	0	0	0
		083	0	0	0	0	.008	.168	.042	.168	.0008	0	0	0	0
	40m	285	0	0	0	0	.0008	.084	.0008	0	0	0	0	0	0
		142	0	0	0	0	.0008	.167	.084	0	0	0	0	0	0
		000	0	0	0	0	.0016	.167	.084	0	0	0	0	0	0

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
135°	1m	000	4.28	9.72	14.83	17.60	21.79	23.05	35.53	*	*	*	*	*	*
		019	4.36	6.11	5.95	6.20	6.79	8.38	13.41	29.34	44.85	14.67	*	*	*
		325	2.93	2.68	2.43	3.02	2.68	3.98	5.20	9.22	9.22	6.29	12.15	50.29	69.57
		290	3.43	2.18	2.35	3.02	4.86	4.69	5.20	14.67	17.60	11.74	23.89	*	*
		176	4.53	5.28	3.52	4.36	6.20	6.79	8.38	6.54	8.80	15.93	23.89	0	0
	5m	115	.502	.42	.67	1.01	1.51	2.35	4.61	9.22	4.19	3.35	5.03	9.47	14.25
		118	.50	.59	.67	.82	1.51	2.35	5.20	10.05	8.80	5.03	5.87	12.15	2.01
		000	.50	.67	.59	1.01	1.51	2.10	4.61	10.05	8.80	5.03	5.45	8.13	11.32
		323	.42	.50	.34	.50	1.17	1.38	3.35	9.22	5.45	3.35	4.36	8.13	18.86
		248	.34	.42	.25	.50	.82	1.26	2.51	4.61	3.77	2.10	3.35	6.29	10.48
	10m	356	.04	.04	.001	.001	.17	.21	.42	3.77	2.18	.84	.42	.42	.42
		312	.04	.008	.001	.001	.17	.21	.42	2.51	1.26	.67	.59	.42	0
		222	.04	.008	.001	.001	.08	.21	.34	2.18	1.47	.42	.50	0	0
		255	.04	.008	.001	.001	.08	.21	.42	2.01	.84	.08	.50	0	0
		000	.04	.008	.001	.001	.17	.25	1.17	4.36	.17	.84	.59	0	0
		040	.04	.008	.001	.001	.04	.13	.01	2.01	.84	.42	.59	0	0
	15m	222	.04	.008	.001	0	0	0	.08	.13	.08	0	.42	.42	.42
		000	.04	.008	.001	.0001	.0001	.08	.17	.84	.84	.0001	.50	.42	.42
		022	.008	.008	.001	0	0	.08	.08	.42	.42	0	.50	.42	.42
		124	.001	.001	.001	0	0	.08	.17	.63	.68	0	.50	.42	.42
		355	.034	.001	.0008	.008	.083	.419	.335	.335	.419	.084	.251	.084	.084
		246	.0008	.0008	.0008	.0008	.0008	.084	.168	.838	.419	.251	.008	.838	.084

θ Depth	ϕ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
20m	339	0	0	0	0	0	0	0	.08	0	0	0	0	0
	000	0	0	0	0	0	0.1	2.0	2.28	0.1	0	0	0	0
	103	0	0	0	0	0.1	1.4	4.5	.08	.08	0	0	0	0
	143	.01	0	0	0	0	0	0	.08	0	0	0	0	0
	184	.017	.0008	0	0	0	.084	.084	.419	.419	.017	0	0	0
	201	0	0	0	0	0	.059	.084	.419	.001	.008	0	0	0
25m	208	0	0	0	0	0	0	0	0	0	0	0	0	0
	182	0	0	0	0	0	0	0	0	0	0	0	0	0
	343	0	0	0	0	0	.084	.0008	0	0	0	0	0	0
	000	0	0	0	0	0	.084	.0008	.0001	.042	0	0	0	0
	090	0	0	0	0	0	.067	.042	.419	.084	0	0	0	0
	110	0	0	0	0	0	.067	.042	.419	.084	0	0	0	0

θ	Depth	φ	400-425	425-450	450-475	475-500	500-525	525-550	550-575	575-600	600-625	625-650	650-675	675-700	700-725
166°	1m	000	4.95	9.47	12.57	9.72	17.6	20.12	33.53	*	*	31.43	30.60	*	*
		082	1.84	1.68	1.93	2.68	2.68	3.98	5.87	10.06	9.22	7.96	5.51	6.28	*
		150	*	5.196	5.700	6.538	6.873	7.711	15.088	39.396	45.264	16.764	*	*	*
	5m	000	.34	.34	.25	.50	.92	1.26	2.51	6.54	3.10	2.77	3.77	6.29	10.06
		205	.34	.50	.34	.80	.92	1.26	2.51	6.29	3.77	4.19	3.35	6.29	11.32
	10m	000	.04	.01	.001	.001	.08	.13	.42	2.01	.84	.25	.59	.42	.42
		270	.04	.01	.001	.001	.08	.13	.42	.84	.84	.08	.42	0	.08
		055	.03	.01	.001	.001	.08	.13	.42	.84	.50	.17	.50	0	.42
	15m	120	.04	.001	.001	.001	.001	.001	.08	.17	.42	.001	.34	.001	.001
		000	.03	.01	.001	.001	.001	.001	.08	.21	.50	.08	.42	.001	.001
	20m	000	0	0	0	0	0	0	.0011	.112	.001	0	0	0	0
	25m	000	0	0	0	.0008	0	.067	.0008	0	.042	0	0	0	0

* Values exceed limitations of standard lamp

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13. ABSTRACT

An underwater spectral radiance meter having a rotating spectral wedge filter and capable of operating to depths of 300 meters was designed and constructed. It was used to obtain measurements of spectral radiance to a depth of 60 meters at two stations in southern Monterey Bay, California, on an overcast day during July 1971. Variations of the spectral radiance distribution with depth were plotted for vertical angles of 0, 45, 90, 135 and 166 degrees at an azimuth angle of zero degrees with respect to the sun.

The results of the measurements are reasonable in all cases and indicate that the spectral wedge filter provides a practical means of determining spectral radiance distributions.

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